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DYNAMOS AND MOTORS
OPERATION OF DYNAMOS AND MOTORS
DYNAMO-ELECTRIC MACHINERY
GEOMETRICAL DRAWING
MECHANICAL DRAWING
STEAM HEATING
STEAM TURBINES

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CONTENTS

DYNAMOS AND MOTORS.

ELECTROMAGNETIC INDUCTION.

1. It has been shown that an electric current circulating around a coiled conductor produces lines of force which thread through the coil, entering at one end and leaving at the other. So long as the current in the coil remains at

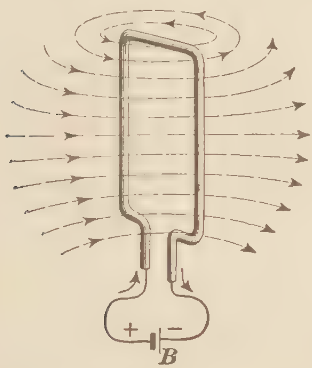

Fig. 1.

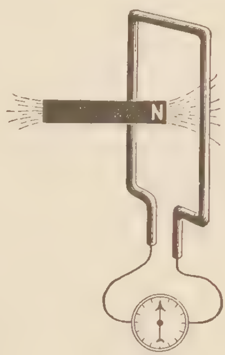

Fig. 2.

a constant strength, the lines of force have direction and position only; unless influenced by some exterior magnetic substance, they do not increase or diminish in number, or change their position relatively to the coil. Fig 1 repre-

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Note.—This section is the same as that formerly entitled *Dynamos and Motors*, Part 2.

sents such a coil around which a current is flowing from the battery *B*. Suppose the battery is disconnected from the coil and a galvanometer for detecting small currents is inserted in its place. A magnetic pole suddenly thrown into the coil, as represented in Fig. 2, will cause a deflection of the galvanometer needle; the needle, however, will return to its original position as soon as the magnet comes to rest. Withdrawing the magnet from the coil also causes a deflection of the needle, but in the opposite direction. In the first case, a momentary current is induced in the circuit, as shown by the deflection of the galvanometer needle while the magnet is being inserted into the coil; this current immediately subsides when the magnet ceases to move. In the second case, the same effects are produced, with the exception that the current induced in the coil flows in an opposite direction to that in the first case.

These induced currents are caused by a change in the number of lines of force which pass through the coil. In passing into or out of the coil, the lines of force from the magnet set up an E. M. F. in that portion of the conductor in which the number of lines of force is changing, and this E. M. F. tends to send a current through the circuit.

2. In place of a small magnetic pole, imagine the coil to be suddenly inserted into a large uniform magnetic

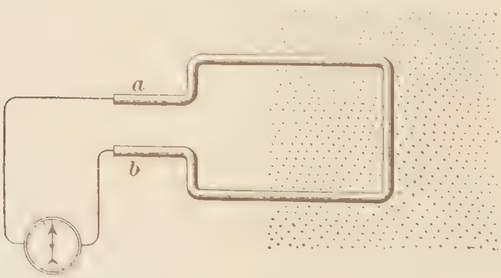


FIG. 8.

field where all the lines of force are parallel to one another The diagram, Fig. 3, represents a cross-sectional view of such a field. The dots represent the ends of the lines of

force; their direction is assumed to be downwards, piercing the paper, or, in other words, the observer is looking along the lines of force toward the face of a south magnetic pole. As the coil enters the magnetic field with its plane at right angles to the lines of force, a current will be induced in the coil and the galvanometer needle will be deflected; this induced current is produced by a change in the number of lines of force which pass through the coil, as in the previous case. Withdrawing the coil from the magnetic field will also induce a current in the circuit, but it will deflect the galvanometer needle in an opposite direction, showing that the current in the circuit is reversed.

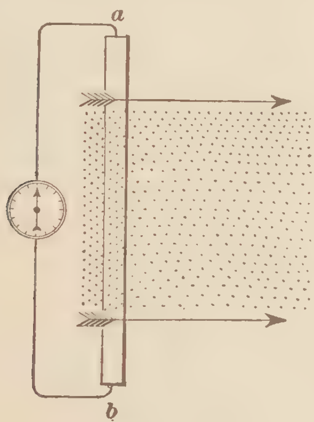


FIG. 4.

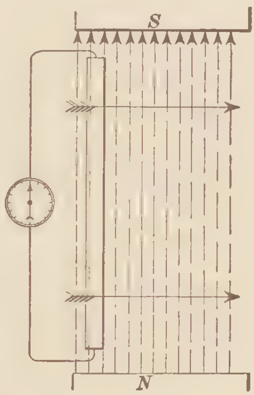


FIG. 5.

If the coiled conductor be straightened out, forming one long conductor, and then moved across the magnetic field at right angles to the lines of force, as represented in Fig. 4, a current will be generated in the circuit. The current, however, immediately subsides when the motion ceases, no matter whether the conductor is in the magnetic field or otherwise. Should the conductor be moved in the magnetic field, with its length parallel to the lines of force, as in Fig. 5, no current will be generated in the circuit. From these two experiments the following principle is deduced: *When a conductor is moved across a magnetic field so that*

it cuts the lines of force, an E. M. F. is generated which tends to send a current through that conductor.

3. In reality, currents generated in a conductor *cutting* lines of force and those *induced* in a coiled conductor by a change in the number of lines of force which pass through the coil are due to the same movement; for, every conductor conveying an electric current forms a closed coil, and every line of force is a complete magnetic circuit by itself. Consequently, when any part of a closed coil is cutting lines of force, the lines of force are passing through the coil in a definite direction and changing at the same rate as the cutting. For example, in Fig. 6 the heavy loop *C. C.* represents a closed coil, and the light loop *L. F.* represents four lines of force. When the two closed loops are brought together, the closed coil is cut at one place *a* by four lines of force, and at the same time the number of lines of force passing through the closed coil increases from nothing to four. In calculations, however, it is convenient to make a distinction between the two cases: in the one case, to consider that the current is *generated* by a conductor of a certain length *cutting* lines of force at right angles; and in the other, to consider that the current in a closed coil is *induced* by a *change* in the number of lines of force passing through the coil.

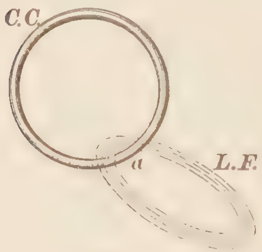


FIG. 6

In these explanations, it must not be forgotten that an electric current is the result of a difference of potential or electromotive force. Consequently, it is not actually a current that is generated in the moving wire, but an electromotive force; for, in all of the previous experiments in which currents are induced or generated in a conductor by the lines of force, if the circuit is opened at any point, no current will flow, but the electromotive force still exists.

4. There are three methods of producing an electromotive force by induction in a coiled conductor; namely, by

electromagnetic induction, by *self-induction*, and by *mutual induction.*

In **electromagnetic induction,** the change in the number of lines of force which pass through the coil is due to some relative movement between the coil and a magnetic field; as, for example, by thrusting a magnet into the coil or withdrawing it, or, again, by suddenly inserting the coil into a magnetic field with its plane at right angles to the lines of force.

5. In **self-induction,** the change in the number of lines of force is caused by sudden changes in a current which is already flowing through the coil itself and is supplied from some exterior source. This exterior current produces a magnetic field in the coil, and so long as the strength of the current remains constant, there is no change in the number of lines of force which pass through the coil. But if the strength of the current is suddenly increased, a change in the number of lines of force occurs; the change in turn *induces* an electromotive force in the conductor, which *opposes* the original current in the coil and tends to keep the current from rising. Its action is similar to that which would take place if some extra resistance were suddenly inserted into the circuit at the instant the strength of the current is increased. The original current eventually reaches its maximum strength in the coil as determined by Ohm's law, but its rise is not instantaneous; it is retarded to a certain extent by this induced electromotive force. If, on the contrary, the strength of the original current is suddenly allowed to decrease, another change is produced in the lines of force which pass through the coil; this new change induces an electromotive force in the coil which acts in the *same* direction as that of the original current and tends to keep it from falling. As in the previous case, however, the original current will eventually drop to its minimum strength, as determined by Ohm's law, but it will fall gradually, and a fraction of a second will elapse before it becomes constant. In short, the current flowing through a

coiled conductor acts as if possessing *inertia;* any sudden change in the strength of the current produces a corresponding electromotive force which opposes that change and tends to keep the current at a constant strength.

6. In **mutual induction,** two separate coiled conductors, one conveying a current of electricity, are placed near each other, so that the magnetic circuit produced by the one in which the current flows is enclosed by the other, as shown in Fig. 7, where the current circulates around the coil P when the circuit is closed at key b. The coil P is called the **primary,** or **exciting, coil;** the other coil S is the **secondary coil.**

Any sudden change in the strength of the current circulating around the primary coil, as, for instance, breaking the circuit at b, produces a corresponding change in the number of lines of force in the magnetic circuit which passes through both coils, and hence an electromotive force is induced in the secondary coil. If the primary circuit is completed at b and the current tends to rise in that coil, the electromotive force induced in the secondary coil causes a current to circulate around in it in the *opposite* direction to the current in the primary coil. If, on the contrary, the circuit at b is suddenly opened and the current in the primary decreases, the induced electromotive force in the secondary causes a current to circulate around in it in the *same* direction as the current in the primary coil.

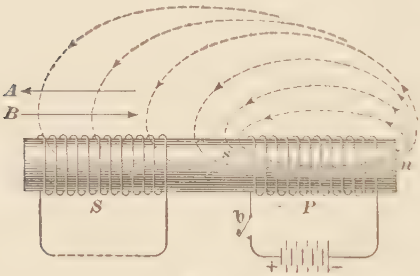


FIG. 7.

To make this clear, suppose, in Fig. 7, the current in the primary coil to be suddenly established by closing the switch at b. The lines of force will surround the conductors and spread out in all directions. The lines of force spreading out

in the direction of arrow A cut the conductors of the secondary coil. The resulting current in the secondary would have the same direction were the lines of force stationary, as shown, and the coil S moved along the core in the direction of arrow B. Then, according to the thumb-and-finger rule, the current will flow in the secondary coil in a direction opposite to that in the primary. Similar reasoning will show that when the primary circuit is broken and the lines of force collapse, the direction of the current in the secondary coil S will be the *same* as that which existed in the primary.

7. The direction of an induced current in a coil depends upon the direction of the lines of force in the coil and whether their number is increasing or diminishing. If these two facts are known, the direction in which the current circulates around the coil is determined by the following rule:

Rule.—*If the effect of the action is to diminish the number of lines of force that pass through the coil, the current will circulate around the coil in the direction of the movement of the hands of a watch as viewed by a person looking along the magnetic field in the direction of the lines of force; but if the effect is to increase the number of lines of force that pass through the coil, the current will circulate around in the opposite direction.*

For example, in the diagram, Fig. 3, when the coil is inserted into the magnetic field, thereby *increasing* the number of lines of force which pass through the coil, the current circulates from b around the coil to a, and thence through the galvanometer to b again; when the coil is withdrawn and the number of lines *diminishes*, the current circulates in the opposite direction, that is, from a around the coil to b, and thence through the galvanometer to a again. That end of the coiled conductor *from* which the current flows *to* the external circuit, as from a through the galvanometer, in the first case, is the *positive* pole or

terminal of the coil; in the second case, *b* is the *positive* pole or terminal.

8. Referring to the straight conductor in which a current is generated by moving it across a magnetic field at right angles to the lines of force, the direction of the current in the conductor depends upon the relation of the direction of the lines of force to that of the moving conductor. The conductor must necessarily be moved across the magnetic field at some angle to the lines of force, and the current generated in the conductor will tend to flow at right angles to the lines of force and at right angles to the direction in which the conductor is moving. In Fig. 4, if the conductor is moved from left to right across the lines of force, the current generated in it will tend to flow upwards through the conductor; that is, from *b* to *a* through the conductor, then from *a* to *b* through the galvanometer. If the conductor is moved in the opposite direction, that is, from right to left, the current in the conductor will tend to flow in a reversed direction, that is, from *a* to *b* through the conductor and from *b* to *a* through the galvanometer. A convenient method for remembering the direction of a current generated in a straight conductor, when the conductor is moved in a magnetic field at right angles to the lines of force, is as follows:

Rule.—*Place thumb, forefinger, and middle finger of the right hand so that each will be perpendicular to the other two; if the forefinger points in the direction of the lines of force and the thumb points in the direction toward which the conductor is moving, then the middle finger will point in the direction toward which the current generated in the conductor tends to flow.*

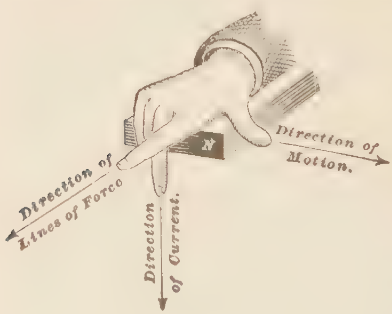


FIG. 8.

For example, in Fig. 8, if a vertical conductor be moved across the front of the north pole N of the magnet in the direction toward which the thumb points, the current generated in the conductor will flow downwards, that is, in the direction toward which the middle finger is pointing.

The summary of these electromagnetic induction experiments can be stated as follows: *Electromotive forces are generated in a conductor moving in a magnetic field at right angles to the direction of the lines of force, or are induced in a coiled conductor when a change occurs in the number of lines of force which pass through the coil.*

PHYSICAL THEORY OF THE DYNAMO.

9. In Fig. 9, a rectangular coil of copper wire is placed in the center of a uniform field with its plane lying perpendicular to the lines of force; in this position, the coil encloses the greatest number of lines of force. A voltmeter $V\ M$ for measuring small E. M. F.'s is connected to the two ends of the coil, as shown in the diagram. The circuit in the voltmeter is kept closed, and any E. M. F. generated in the conductor will be indicated by the deflection of the index needle.

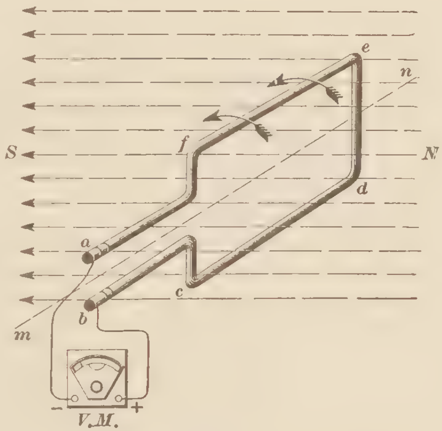


FIG. 9.

So long as the coil remains at rest in the magnetic field no E. M. F. is generated; but imagine the coil to be rotated on an axis in its own plane, such as represented by the broken line $m\,n$, in the direction indicated by the curved

arrows. As the coil starts to rotate, its sides *c d* and *e f* begin to cut the lines of force at right angles, thus generating an E. M. F. in each side. From the thumb-and-finger rule, the E. M. F. generated in the upper side tends to cause a current to flow from *f* to *e*; and in the lower side, the current tends to flow from *d* to *c*. Hence, the E. M. F.'s generated in the two sides are added together, and the total E. M. F. generated by the coil is indicated by the *V M* between *a* and *b*, the end *b* forming the *positive* terminal of the coil. If the coil is rotated at a uniform angular velocity, that is, if the speed of rotation is constant throughout each revolution, the deflection of the voltmeter becomes greater as the coil revolves from its vertical position until it passes through one-quarter of a revolution and reaches a position where its plane lies parallel to the lines of force.

10. The diagram, Fig. 10, represents an end view of the coil in two positions: position *1*, as shown by the dotted lines, represents the coil standing vertically at the moment of starting, and position *2*, as shown by the full lines, represents the coil lying horizontally after passing through one-quarter of a revolution. The deflection of the needle, if read at frequent intervals during this quarter of a revolution, gradually increases, beginning at zero in position *1* and reaching a maximum at position *2*. The gradual rise of the E. M. F. in the circuit while the coil is revolving from position *1* to position *2* can be graphically shown by means of cross-section paper, Fig. 11. The horizontal divisions represent equal intervals of time, and the sum of the divisions between *A*

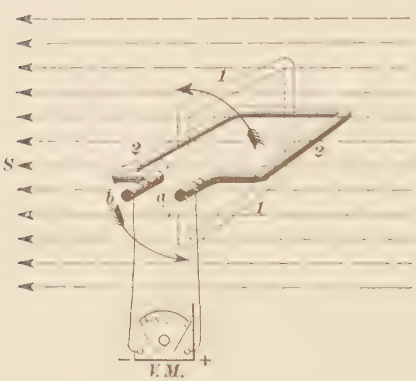


FIG. 10.

and *B* is the total time occupied by the coil in revolving one-quarter of a revolution; the vertical divisions represent E. M. F., and the sum of the divisions between *A* and *Y* is the total E. M. F. that is being generated in the coil when it is passing through position *2*. The vertical distances between the line *A B* and the curved line represent the E. M. F. which is being generated in the coil at every instant during its rotation between positions *1* and *2*. For example, let each vertical division represent 2.5 volts; then, the distance between *A* and *Y* represents 10 volts. When the coil has revolved one-third of the distance between positions *1* and *2*, Fig. 10, it has consumed one-third of the time; hence, at this instant the E. M. F. that is being generated in the coil is represented by the number of divisions between the line *A B* and the curved line, at one-third the distance toward *B*, which equals two divisions; or $2 \times 2.5 = 5$ volts. When the coil travels two-thirds the distance between positions *1* and *2*, the E. M. F. that is being generated at that instant is represented by the number of divisions between the line *A B* and the curved line at two-thirds the distance toward *B*, which equals about 3.48 divisions, or $3.48 \times 2.5 = 8.7$ volts.

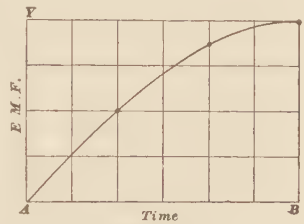


FIG. 11.

11. After the coil passes through position *2*, the E. M. F. that is being generated begins to diminish, and by the

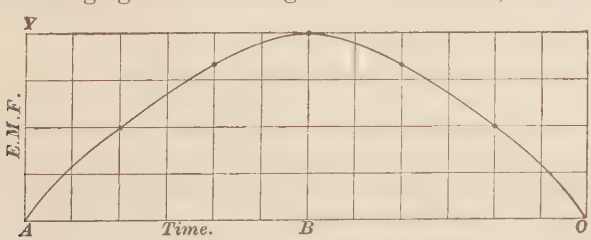


FIG. 12.

time the coil has revolved one-half of a revolution and is once more in a vertical position, the E. M. F. falls to zero

again. The E. M. F. that is being generated at every instant during one-half of a revolution can be shown by a continuation of the curve on cross-section paper, Fig. 12. The sum of the divisions between A and C represents the total time occupied by the coil in rotating one-half of a revolution. It will be seen that the maximum E. M. F. that is being generated at any instant is at position *2*, Fig. 10, which corresponds to B, Fig. 12. In this position the plane of the coil lies parallel to the lines of force, and its sides, corresponding to $c\,d$ and $e\,f$, Fig. 9, are cutting the lines of force at exactly right angles. The sides of the coil at the moment of passing through this position are cutting more lines of force for equal intervals of time than in any other position during the first half of a revolution.

From this fact the following principle is deduced: *The E. M. F. generated in a moving conductor cutting lines of force at right angles is directly proportional to the rate of cutting.* Suppose, for example, that a magnetic field contains 100,000 lines of force, and that a conductor is moved across the field at right angles in such manner as to cut every line of force. If the time occupied by the conductor in passing across the field is one second, then the rate of cutting is 100,000 lines per second; or, if it occupied two seconds, the rate of cutting is 50,000 lines per second, and so on. The E. M. F. generated in the former case is twice as great as that generated in the latter. The method for determining the number of lines of force in a magnetic field will be described later.

12. Fig. 13 shows the coil after being rotated one-half of a revolution. As soon as the coil starts on the last half of the revolution, its sides $c\,d$ and $e\,f$ cut a few lines of force, and, consequently, an E. M. F. is generated in each side. The E. M. F., however, tends to cause a current to flow in the coil in an opposite direction to that which tends to flow during the first half of the revolution. For, by applying the thumb-and-finger rule, the E. M. F. generated in the sides tends to cause a current to flow from c to d and

from e to f; the end a of the coil, which in the first half of the revolution was the negative terminal of the coil, now forms the positive terminal. Hence, in order to allow the current to enter the positive binding post of the voltmeter, the connections must be reversed.

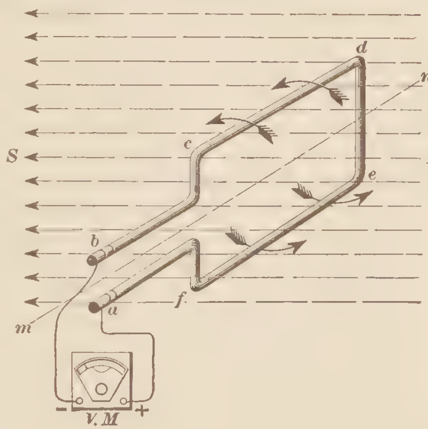


FIG. 13.

The E. M. F. that is generated as the coil is rotated through the last half of the revolution gradually rises as in the first half, reaching a maximum height when the plane of the coil lies parallel to the lines of force, and afterwards falling to zero again as the coil reaches a vertical position. In Fig. 14, the E. M. F. that is generated in the coil at every instant during one complete revolution is graphically shown by

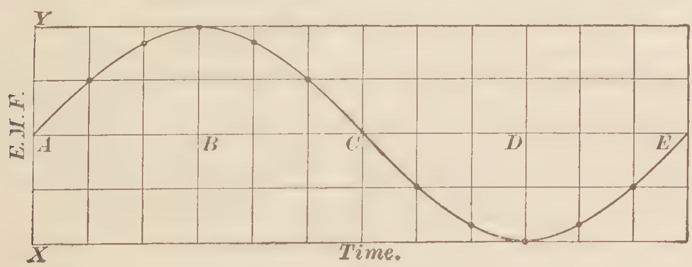


FIG. 14.

the use of the cross-section paper. The sum of the divisions between A and E represents the time occupied by the coil in making one complete revolution; the divisions between A and Y represent the E. M. F. which tends to send a current in one direction through the coil, as in the first half of the revolution, and the divisions between A and

X represent the E. M. F. which tends to send a current through the coil in an opposite direction, as in the last half of the revolution. The divisions between the curved line and the line $A E$, or **base line,** give the E. M. F. that is being generated in the coil at any instant during the revolution, and the direction in which the E. M. F. tends to act depends upon whether this E. M. F. falls above or below the base line $A E$. For convenience, let the direction in which the E. M. F. tends to act in the first half of the revolution be called the **positive** (+) **direction,** and in the last half the **negative** (−) **direction.** For example, the E. M. F. that is generated in the coil when it has revolved three-quarters of a revolution is represented by the distance between D and the curved line, which, in this case, is two divisions; and since these divisions are below the base line, the direction in which this E. M. F. tends to act is negative.

13. In Fig. 15, instead of connecting the external circuit directly to the ends of the coil, suppose the wires o and p to be brought to two brushes r and s, which lie in a horizontal position and bear on the two *collector rings* x and y, respectively. These collector rings, it will be seen, are connected to the two ends of the coil; x to a and y to b.

The resistance of the entire circuit, including the coil, ammeter, collector rings, and brushes, is comparatively small; hence, any E. M. F. generated in the coil causes a corresponding current to flow through the circuit, and its strength is indicated by the ammeter $A. M.$ When the coil begins to revolve, a feeble E. M. F. is generated in it, as previously described. This E. M. F. causes a corresponding current to flow through the circuit in a positive direction; as the E. M. F. becomes larger, the strength of current in the circuit becomes greater, and vice versa. After the coil is rotated one-half of a revolution and the direction in which the E. M. F. tends to act becomes negative, the direction of the current in the circuit is also reversed. If there is no self-induction to retard the rise and fall of the

current in the circuit, the strength of the current in the circuit at any instant is exactly proportional to the E. M. F. that is being generated in the coil at that moment; for, according to Ohm's law, the strength of current in any

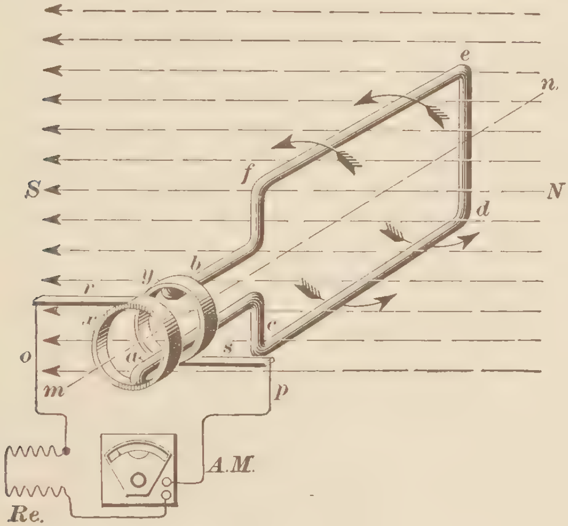


FIG. 15.

circuit is equal to the E. M. F. generated in that circuit, divided by its resistance. The rising and falling and also the reversing of the current in all parts of the circuit for each revolution, therefore, can be represented graphically on cross-

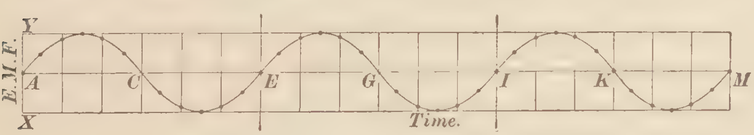


FIG. 16.

section paper in the same manner as previously described for the E. M. F. Fig. 16 represents the rising, falling, and reversing of the current in the circuit for three complete and consecutive revolutions of the coil; the divisions between

A and E, E and I, and I and M represent the time of each revolution, respectively. The divisions between the base line $A\ M$ and the curved line above the base line represent the strength of current in the circuit when the direction of flow is positive, and those below represent the strength of current when the direction of flow is negative. Revolving the coil, therefore, at a constant speed generates a current in the circuit, which, in every complete revolution, rises gradually to a maximum strength and falls to zero in one direction, then is reversed, and the same effect is produced in the opposite direction. In other words, the current in the circuit *alternates* from one direction to the opposite direction in each revolution.

An electric current of this character flowing through a circuit is termed an **alternating current.**

14. The next step is to demonstrate the principle of changing, or *commuting*, this alternating current into a *continuous*, or *direct*, current; that is, a current which always

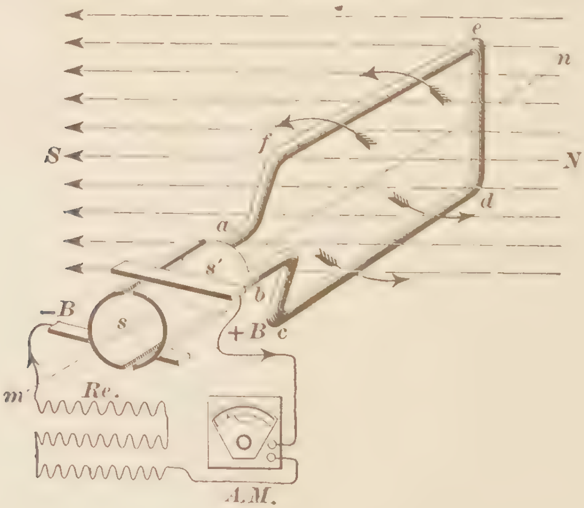


FIG. 17.

flows in the same direction through the external circuit. In Fig. 17, the two ends of the coil are fastened to two

halves s and s' of a metallic tube. These halves are called **segments,** and in this case are separated by a small air space, the rigidity of the coil holding them apart. The combination of the two segments, or, in fact, any number of segments held together in this position, is called the **commutator.** Two copper strips $+B$ and $-B$, called **brushes,** press against the segments, and are held in a horizontal position while the coil is rotated. The brushes rub, or *brush*, against the segments and make electrical contact only.

When the coil is in a vertical position, as represented in the figure, both brushes rest against both segments; but as soon as the coil starts on the first half of a revolution in the direction indicated by the arrows, the brush $-B$ leaves segment s' and rubs only against segment s; brush $+B$ leaves segment s and rubs only against segment s'. As previously described, the electromotive force that is generated in the coil during the first half of a revolution causes a current to flow from a through the coil to b, and from b through the external circuit to a again, making b the positive end of the coil. Hence, in this case, $+B$ is the positive brush, and the current in the external circuit flows in the direction indicated by the arrowheads. As the coil starts on the last half of a revolution, the direction of the current in the coil changes, and a becomes the positive end of the coil. But the current in the external circuit continues to flow in the same direction as in the first half of the revolution, and $+B$ remains the positive brush. For, at the beginning of the second half of a revolution, when end a of the coil becomes positive, $-B$ leaves segment s and makes contact with s', and $+B$ leaves s' and makes contact with s. Hence, the current in the external circuit, during a complete revolution, flows from the positive brush $+B$ through the ammeter $A\ M$ and the resistance Re to the negative brush $-B$; that is, the current in the external circuit flows continually in the same direction, while the current in the coil itself flows in two directions during every revolution. But the strength of the current in the external circuit is by

no means constant; it rises from zero to a maximum strength and falls again to zero twice in every revolution, but always in the same direction. The effect is graphically shown in Fig. 18 by the use of cross-section paper, where the divisions between A and E, E and I, and I and M represent the time occupied by the coil in rotating each revolution, respectively, and the vertical divisions between the base line $A\ M$ and the curved line represent the strength of

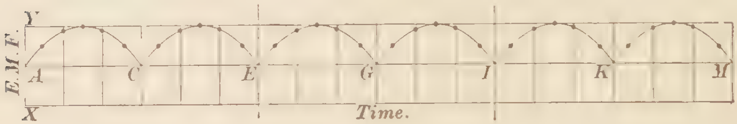


FIG. 18.

the current in the external circuit at every instant during the three revolutions. The effect is produced continually in the external circuit if the coil is rotated at a constant speed. These impulses in the strength of the current give it the name of **pulsating current.**

A consideration of the preceding paragraphs will show the student that direct-current dynamos require commutators, while alternating-current dynamos employ only collector rings.

15. In Fig. 19, two separate coils are placed in a magnetic field at right angles to each other. Four metallic segments s, s', s'', and s''' are cut from a cylindrical ring to form the commutator, and are separated from one another by small air spaces; the two ends of each coil are connected to two opposite segments in such manner that an imaginary diameter connecting the two segments together would lie at right angles to the plane of their coil, as shown in the figure. Two metallic brushes $+B$ and $-B$ rub against the commutator, touching the two segments diametrically opposite to each other. A line drawn through the center of the commutator, connecting the contact ends of the two brushes, should lie at right angles to the direction of the lines of force in the magnetic field in which the coils are

rotated. As the two coils and commutator are rotated in the direction indicated by the arrows, the two brushes rub against the segments consecutively and always make contact with the two opposite ones. The brushes are connected to an exernal circuit consisting of the ammeter *A M* and the resistance *Re*. At the position of the coils in the figure, the brushes are rubbing against the segments *s* and *s″*, which

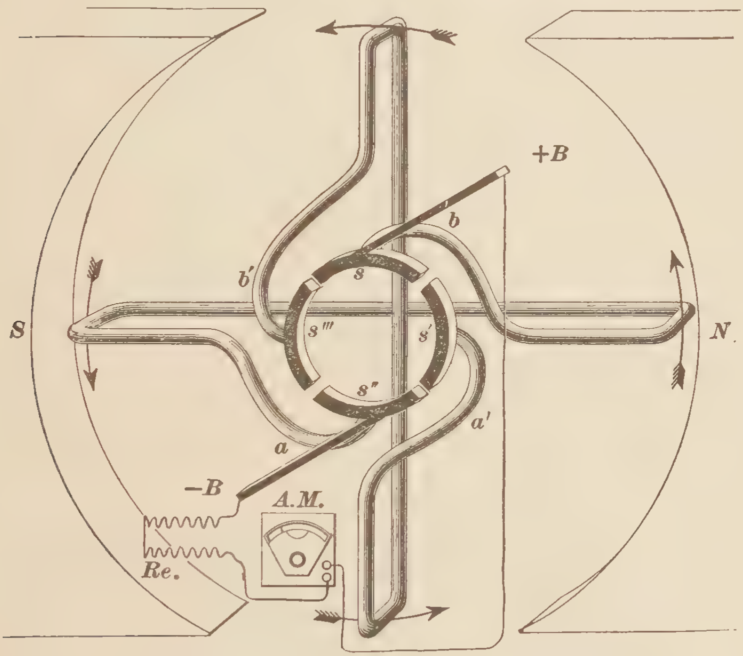


Fig. 19.

are connected to the ends of the horizontal coil. From previous experiments, it will be seen that at this position the horizontal coil is generating a maximum E. M. F., which tends to send a current from *a* through the coil to *b*; hence, the current is flowing in the external circuit from $+B$ to $-B$. After the coils and commutator are rotated one-eighth of a revolution from this position, and the E. M. F. in the coil begins to fall, the brush $+B$ passes from segment *s*

to segment s', and brush $-B$ passes from s'' to s'''. The E. M. F. that is being generated in the vertical coil when the brushes pass to segments s' and s''' is nearly maximum. Consequently, the strength of the current which has been flowing in the external circuit from the other coil does not decrease to zero; it only diminishes a small amount before the segments of the next coil make contact with the brushes, when it begins to increase again. It will be seen that during one complete revolution of the moving parts, the brushes passed over four segments; also that the direction of the current produced is *from* the coils *to* brush $+B$, and *into* them *from* brush $-B$. These actions produce a direct current in the external circuit which flows continually in the same direction, but whose strength fluctuates, or changes, regularly four times in every revolution.

By resorting again to the cross-section paper, the fluctuations of the current in the exterior circuit can be graphically

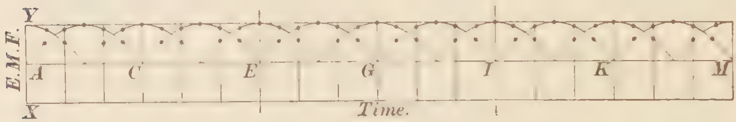


FIG. 20.

shown. In Fig. 20, the divisions between the base line *A M* represent the strength of current in the external circuit for three complete revolutions. So long as the speed of rotation is uniform, the current decreases to a little less than three-quarters of its maximum strength, provided, of course, the resistance of the external circuit is not altered; the dotted curved lines indicate how the strength of the current would fall to zero if only one of the coils were used.

The strength of such currents can be made more uniform and the pulsations less noticeable by using several coils connected to the segments of a commutator, the planes of the coils being placed at equal angles from one another. A continuous current of uniform strength is known as a constant current.

16. It has already been stated that the *permeability* of iron is much greater than that of air; or, in other words, if a piece of iron were inserted in a magnetic field, the number of lines of force in the field would be greatly increased. Hence, if the coils are wound around a cylindrical drum of iron, as shown in Fig. 21, the number of lines of force passing through the coils is increased, and the E. M. F. that is generated is greater, since the E. M. F. is proportional to the rate of cutting of the lines of force. The coils are entirely insulated from the iron core by some non-conducting material, such as cloth, mica, or paper; otherwise, they would be short-circuited on the core; that is, the current would flow through the iron instead of passing into the external circuit. The other conditions remain unchanged; i. e., the lines of force have the same direction as in the previous cases, and remain in one position while the coils are revolved. The core should not be made of one solid mass of iron; for, if such were the case, the core, when rotated, would act as a large closed conductor, cutting lines of force at right angles. The E. M. F. generated in the core would cause **local,** or **eddy,** currents to flow through the iron itself, heating it and uselessly dissipating a large amount of energy. An idea of how these

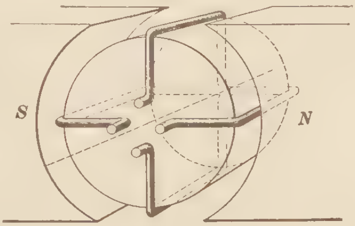


FIG. 21.

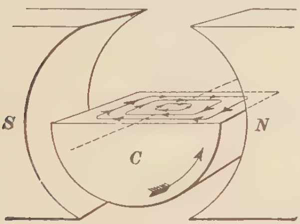


FIG. 22.

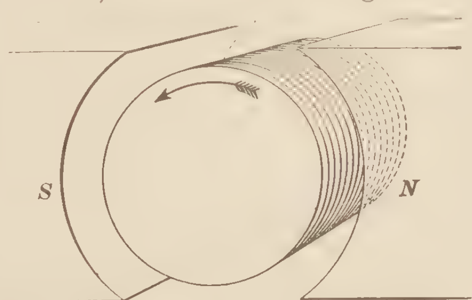


FIG. 23.

eddy currents would circulate in a solid iron core can be formed from Fig. 22. *C* represents the solid iron core, the top half of which is cut away. The curved lines and arrowheads show the direction in which the eddy currents would flow if the core were rotated in the direction indicated by the large arrow. To overcome this difficulty, the core is made of a large number of round, thin iron plates, or disks, each disk being insulated from the adjacent ones by some non-conducting material, such as tissue paper, insulating japan, or simply by the oxide formed on the surface of the disk during the process of its manufacture. The disks should be fastened together in such a manner that, when rotated in a magnetic field, their flat surfaces are parallel to the direction of the lines of force and to the direction of rotation, as shown by Fig. 23. Dividing the core into disks in no way diminishes the magnetic permeability of the iron, and for all practical purposes, it prevents the eddy currents from flowing. A core made in this way is said to be **laminated.**

17. Iron cores are generally made in two styles: **drum** or **ring.**

A drum core may be defined as a laminated cylinder, the length being generally greater than the diameter, such as shown in Fig. 23.

A ring core may be defined as a laminated rim of rectangular cross-section, such as *R* in Fig. 24.

An iron core inserted between the poles of a magnet not only increases the total number of lines of force from the magnet, but attracts nearly all the stray lines of force from the surrounding air; that is, the lines of force prefer to complete their circuit through iron rather than through air or other non-magnetic substances. For example, in Fig. 24, an iron ring *R* is placed between the poles *N* and *S* of a magnet; the lines of force pass out from the north pole *N* and enter the iron ring. When passing across the air gap, they are uniformly distributed, but after entering the ring, they crowd together and remain in the iron as long as possible. If the total number of the lines of force is large in

comparison with the cross-sectional area of the iron ring on $x\,y$, a few will pass through the air in the inside of the ring,

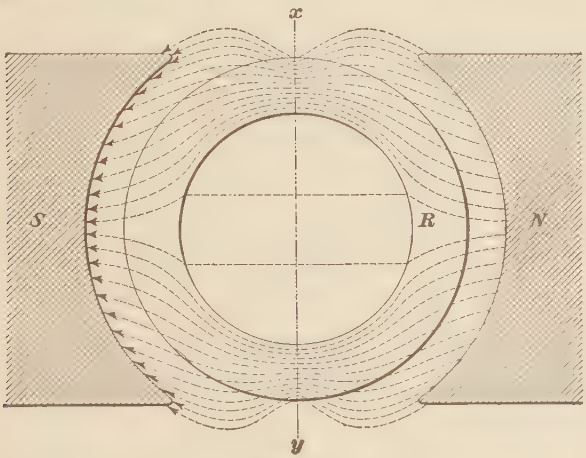


Fig. 24.

as shown in the cut; but in most cases the number of such stray lines is not large enough to be considered. Conse-

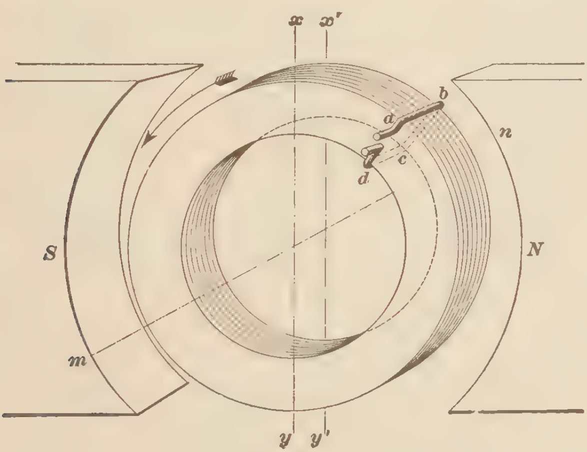


Fig. 25.

quently, in Fig. 25, if a loop of insulated wire *a b c d* is wound around the iron ring, and the ring and loop are

rotated on a central axis *m n* like the rim of a flywheel, only that part of the loop from *a* to *b* is cutting lines of force; the rest of the loop, from *b* to *c* and from *c* to *d*, is inactive in relation to the lines of force. From the thumb-and-finger rule it will be seen that the E. M. F. generated in the side *a b* of the loop tends to send a current from *b* to *a* during the first half of the revolution from *y y'* to *x x'*, and in the opposite direction during the last half.

18. No current will flow from the loop through the external circuit when the ring is made of some non-magnetic substance, as will be understood from the following explanation: Imagine the iron ring to be moved from the field without disturbing the loop; then, imagine the loop to be rotated around the axis *m n* in precisely the same path

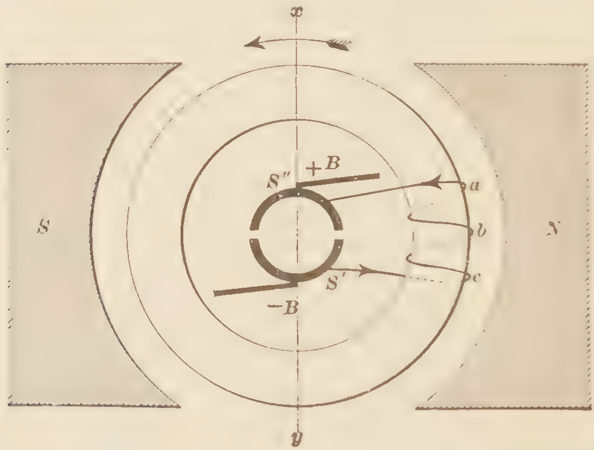


FIG. 23.

as before. The lines of force in the field are now uniformly distributed, and as the loop moves, the part between *c* and *d* will cut the lines of force at approximately the same rate as the part between *a* and *b*. But the electromotive forces generated in the two parts tend to oppose each other; that is, the E. M. F. generated between *a* and *b* tends to act away from *b*, and that generated between *c* and *d* tends to

act away from c. Hence, there is no difference of potential between the ends a and d, and no current will flow through an external circuit.

After replacing the iron ring again, suppose the insulated wire to be wound around it several times, as represented in Fig. 26, and the ends of the coil connected to two metallic segments S' and S''. By applying the rule, it will be seen that the electromotive forces generated in the separate turns at a, b, and c are added together; that is, the difference of potential between the brushes $+B$ and $-B$ is the sum of the electromotive forces generated in the separate turns. The current obtained from such a coil is *pulsating*. For all

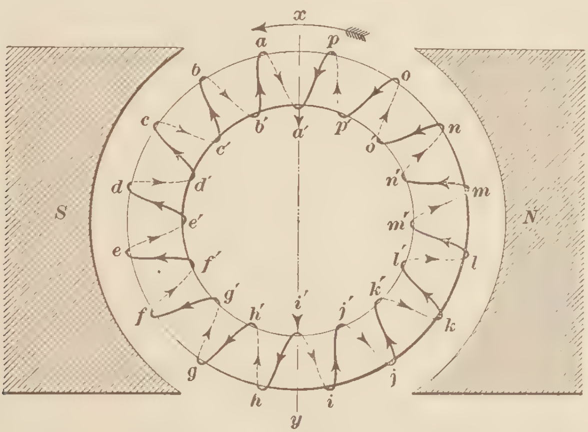


Fig. 27.

practical purposes, the total E. M. F. generated by such a coil is directly proportional to the number of turns. For example, if a coil of 1 turn generates 2 volts at a certain position and angular velocity, then a coil of 4 turns will generate 8 volts under the same conditions, and so on. But the turns in each coil must be approximately close together. For, if the coil is wound over a large portion of the ring, some of the turns, at one position of the coil, will be cutting the lines of force as they pass out from the north pole, while other turns will be cutting the lines of force as they enter the south pole, the electromotive forces generated in the

two cases being opposed to each other. This action will be readily understood by winding the entire core with one large coil of several turns and connecting the two ends of the coil together, as represented in Fig. 27. This is known as a *ring* winding, or one in which the conductors are wound in the form of a helix on a ring core. At the instant the ring and coils reach the position shown in the figure, the E. M. F. generated in the separate turns tends to act in the direction indicated by the arrowheads upon the winding. No current can flow around the coil, because the electromotive forces generated in the two halves act toward each other at a' and away from each other at i'.

19. It is possible, however, to obtain a continuous current from the coil by the addition of a commutator with several segments, as will presently be seen. If the ends of

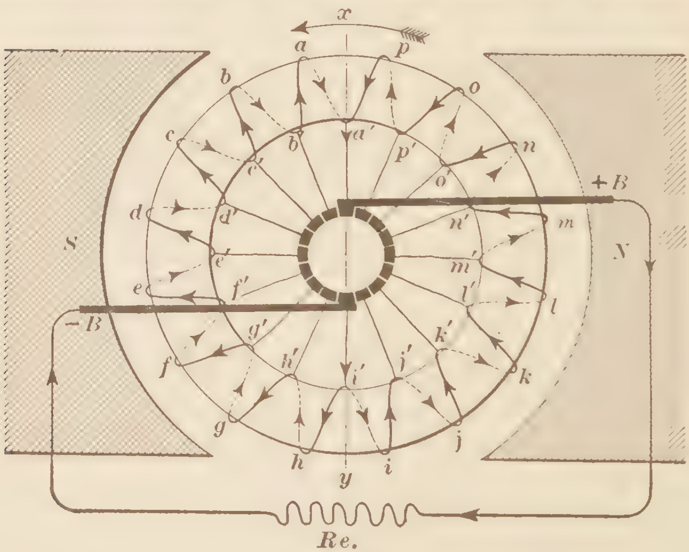


FIG. 28.

a voltmeter are touched to a' and i' during the instant the coil occupies the position in Fig. 27, a difference of potential between the two points will be indicated, a' being the positive point and i' the negative. Hence, if these two

points are connected to an external circuit, a current will flow through it from a' to i', while the coil is at the position shown in the figure. As soon, however, as the coil is rotated about one-sixteenth of a revolution, the difference of potential between a' and i' will begin to fall, and the greatest difference will now be found between p' and h'. About another sixteenth of a revolution will bring the greatest difference of potential between o' and g', and so on. In short, as the coil is rotated, the greatest difference of potential will always be found between any two turns situated diametrically opposite each other when they pass through the vertical diameter $x y$. The next operation is to provide some means to utilize this difference of potential between each pair of turns as they arrive in a vertical position. This is accomplished by connecting each turn to a separate segment of a commutator by a small conductor, and allowing two brushes to rub against the commutator at two points diametrically opposite each other on the vertical diameter $x y$, Fig. 28. From an examination of the figure, it will be seen that the two halves of the coil are connected in parallel or multiple; that is, the current divides at i', one half passing through the turns i, j, k, l, etc. and the other through h, g, f, e, etc. to a', where it again unites. The maximum E. M. F. that is obtained from the coil is equal, therefore, to the E. M. F. generated in one-half of the coil. This statement will be better understood by comparing the coil to a battery of voltaic cells connected in multiple-series. For example, in Fig. 29, the separate cells from a to h, inclusive, correspond to the separate turns on one half of the coil, and the cells from i to p correspond to the turns on the other half. The total E. M. F. of the above battery is equal to the E. M. F. of either of the two sets which are connected in parallel; and the total E. M. F. of either of the two sets is

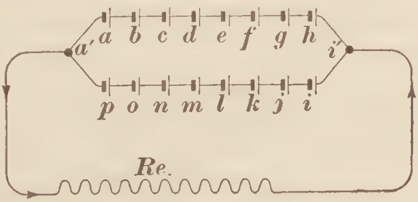


FIG. 29.

the product of the E. M. F. of 1 cell and the number of cells which are connected in series, as from a to h, inclusive.

If a comparatively large number of turns and segments is used, the current flowing from $+B$, Fig. 28, through the external circuit to $-B$ will be practically continuous, that is, non-pulsating; the fluctuations caused by the brushes when passing from one segment to another are extremely minute, and produce no appreciable change in the strength of the current in the external circuit.

20. A conductor wound upon a core in the manner shown in Figs. 27 and 28 is termed a **closed-coil winding,** since all the turns are connected together in one *continuous*, or *closed*, coil, and the current is obtained from it by tapping into each turn or set of turns. In the case where the turns or sets of turns are separate and distinct from one another and their ends are connected to opposite segments of a commutator, as in Figs. 19 and 26, the winding is termed an **open-coil** winding.

21. A *closed-coil winding* can be applied to a cylindrical drum core, as previously described, and a continuous non-pulsating current obtained from the brushes, as in the case of the ring core. The method of winding is somewhat similar to that of the ring, and each turn or set of turns is tapped into and connected to the segment of a commutator by a separate lead, as will be seen from the diagram, Fig. 30. This is known as a drum winding, or one in which the conductors are wound longitudinally upon the surface of a drum core. A drum winding may also be applied to a ring core, as will be seen. The conductor is started at any convenient place on the core, as, for example, at a, and wound across the face of the drum to the rear end; then, wound nearly diametrically across the end, and from there along the face of the core to the front end at a'. From a', the conductor is wound across the front end to a point somewhat in advance or behind the original starting point a, as, for example, to b; from b it makes another complete turn in like manner, which is followed by a third, and so on, until

the last turn is connected to the first by joining the two ends of the coil together at *a*. A separate lead *L* is tapped into the conductor at every complete turn where it is wound across the front end of the core and connected to the separate segments of a commutator. From an examination of the diagram, it will be seen that only a part of the wires on the face of the drum are cutting the lines of force as they enter and pass out of the core at any one instant during a revolution. At the position represented, the wires *e'*, *a*, *f'* and *b'*, *e*, *a'* are the inactive ones, so far as the lines of force

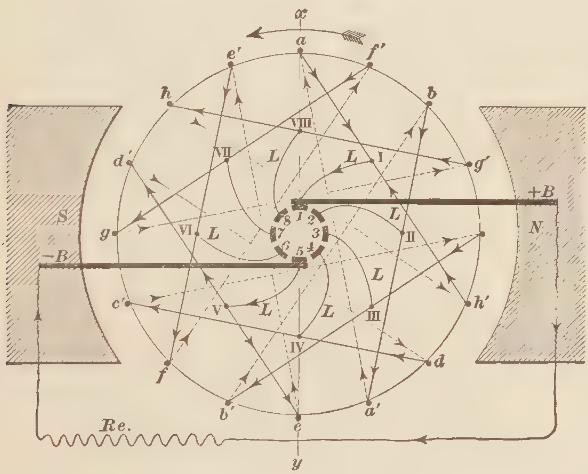


FIG. 30.

are concerned; but they still perform the important function of completing the circuit for the current. The parts of the core where the wires are not cutting the lines of force as the core is rotated are called the **neutral spaces**; and the two opposite parts of the commutator to which the coils are connected are called the **neutral points** of the commutator. Each individual wire becomes inactive twice during every revolution and passes through two neutral spaces; but this fact does not change the positions of the neutral spaces—they lie on an imaginary diameter approximately

perpendicular to the lines of force. This same effect takes place in the commutator, i. e., each segment passes through two neutral points during one complete revolution, but the neutral points remain in a fixed position relative to the neutral spaces of the core. The neutral segments of the commutator, at any instant during a revolution, are those segments which are connected to the wires passing through the two neutral spaces at that instant. The neutral points, however, can be shifted to different points around the commutator by changing the leads from the coil to the segments. For example, in Fig. 30, the two neutral points lie opposite each other on the commutator along the vertical diameter $x\,y$. But if the lead from I is connected to segment No. *7*, instead of No. *1*, and the lead from II to segment No. *8*, and so on around the commutator, then the two neutral points will lie opposite each other on the commutator along a horizontal diameter, and in order to collect any current from the commutator, the brushes $+B$ and $-B$ must be shifted around a quarter of a revolution to these new neutral points.

The current flowing through the winding divides at one neutral space and flows through the coil in opposite directions, uniting again at the other neutral space, as indicated by the arrowheads. According to the thumb-and-finger rule, the current in all the active wires in front of the north pole flows along the periphery of the core towards the observer; that in the wires in front of the south pole flows away from the observer.

22. The next step is to determine the magnitude of the E. M. F. in volts generated in a closed coil. As previously stated, the E. M. F. generated in a conductor cutting lines of force at right angles is proportional to the *rate of cutting.* Consider the case of a single conductor moving across a magnetic field in which the total number of lines of force is known; the rate of cutting is equal to the total number of lines of force cut by the conductor divided by the time required to cut them. This may be expressed in the form of

an equation: thus, *rate of cutting* $= \frac{N}{t}$, where N is the total number of lines cut and t is the time required to cut them. By definition, *one volt* is that E. M. F. generated in a conductor when it is cutting lines of force at the rate of one hundred million (100,000,000) per second. Hence, $E = \frac{N}{10^8 t}$, where E is the E. M. F. in volts and t the time in seconds since $100{,}000{,}000 = 10^8$.

For example, suppose a magnetic field contains 4,500,000 lines of force, and a conductor cuts the total number in the same direction in 1.5 seconds. The E. M. F. that is being generated in the conductor is equal to .03 volt, since $E = \frac{N}{10^8 t}$ $= \frac{4{,}500{,}000}{100{,}000{,}000 \times 1.5} = .03$ volt.

When two or more conductors are cutting lines of force at equal rates, the E. M. F. obtained by connecting them in series is equal to the E. M. F. developed by one conductor multiplied by the number of conductors. Consequently, if S is the number of conductors in series, then $E = \frac{N\,S}{10^8 t}$, where E is the total E. M. F. in volts that can be obtained from S conductors cutting N lines in t seconds. For example, if 8 conductors are moved across the magnetic field containing 4,500,000 lines of force in 1.5 seconds, and they are connected in series, then $E = \frac{N\,S}{10^8\,t} = \frac{4{,}500{,}000 \times 8}{100{,}000{,}000 \times 1.5}$ $= .24$ volt.

Next, imagine these 8 conductors to be moved across the magnetic field in the same direction at the rate of 30 times per second for 1.5 seconds; then, the number of lines cut in one second is $4{,}500{,}000 \times 30 = 135{,}000{,}000$, and the total number of lines cut in 1.5 seconds is, therefore,

$$135{,}000{,}000 \times 1.5 = 202{,}500{,}000. \quad \text{Hence,}$$

$$E = \frac{(N\,n\,t)\,S}{10^8\,t} = \frac{202{,}500{,}000 \times 8}{100{,}000{,}000 \times 1.5} = 10.8 \text{ volts.}$$

Here $n =$ the number of times per second that one conductor cuts the lines of force.

But, in general, the E. M. F. that is obtained from several conductors connected in series moving continually across the same magnetic field at a constant number of times per second is independent of the length of time the operation is continued. For, in the above equation, $E = \frac{(N n t) S}{10^8 t}$, the two t's cancel each other, leaving the equation $E = \frac{N S n}{10^8}$. In the above example, for instance, so long as the 8 conductors are moved across the magnetic field at the rate of 30 times per second, the E. M. F. generated in them is always 10.8 volts, no matter whether the operation is continued for 1.5 seconds or for 1 hour. The time of 1.5 seconds was used merely to make the demonstration clearer by using a specific value for t.

23. The equation $E = \frac{N S n}{10^8}$ can now be applied with some modifications to the closed-coil conductor wound upon either the ring or drum core. The ring core, Fig. 28, will first be considered. In the equation, E is the maximum E. M. F. in volts that is obtained from the brushes $+B$ and $-B$ when the core is revolved; N is the total number of lines of force passing from the north pole through the core to the south pole. Each wire, therefore, on the periphery of the core cuts the total number of lines twice during every revolution; or, in other words, each outside wire cuts $2N$ lines of force per revolution. S is the number of outside wires on the periphery through which the current flows in *series*, and n is the number of complete revolutions per second of the core. Therefore, the maximum E. M. F. in volts that is obtained from the brushes is found by the formula

$$E = \frac{2 N S n}{10^8}. \qquad \textbf{(1.)}$$

That is to say, *the E. M. F. obtained from a number of*

conductors connected in series and moved across a magnetic field is equal to twice the number of lines of force multiplied by the number of conductors in series and by the revolutions per second of the core, divided by 100,000,000. For example, assume the total number of lines N passing from the north pole through the core to be 3,000,000, or $N = 3{,}000{,}000$. In the diagram, Fig. 28, there are 8 outside wires in series, or $S = 8$. If the core is rotated at 2,100 revolutions per minute, $n = \frac{2{,}100}{60} = 35$ revolutions per second. Substituting the values in the formula gives $E = \frac{2\,N\,S\,n}{10^8}$ $= \frac{2 \times 3{,}000{,}000 \times 8 \times 35}{100{,}000{,}000} = 16.8$ volts, or the difference of potential between the brushes $+B$ and $-B$ on open circuit. The difference of potential between the brushes when the external circuit is closed is somewhat smaller than when no current is flowing; because, as in the case of the voltaic cell, a part of the total E. M. F. developed is required to overcome the internal resistance of the coil itself.

The formula $E = \frac{2\,N\,S\,n}{10^8}$ holds equally true for the drum core, Fig. 30. In both cases, the number of outside wires through which the current flows in *series* is equal to one-half the total number of outside wires. Hence, by using the same magnetic field and rotating the cores at equal speeds, the E. M. F. generated in both cases will be equal.

24. The foregoing articles demonstrate the elementary principles and physical theory of a *dynamo*. A **dynamo**, therefore, is a machine for converting mechanical energy into electrical energy by electromagnetic induction. It has three essential features, viz.: (1) a magnetic field; (2) a conductor, or several conductors, called an **armature**, in which the electromotive force is generated by some movement relative to the lines of force in the magnetic field; and (3) a *commutator*, or a *collector*, from which the current is collected by two or more conducting brushes.

In all dynamos, the magnetic field is produced either by a permanent magnet or by an electromagnet, and they are classified accordingly; for present purposes, however, it is sufficient to consider only the uniform magnetic field lying between the poles of some large magnet. In the preceding article, the armature core and commutator were assumed to be fastened rigidly to a shaft and the shaft supported by suitable bearings in such a position that the core would rotate in the magnetic field with its axis of rotation at right angles to the lines of force. The shaft with core and commutator was assumed to be rotated by some exterior mechanical power. The armature conductors were wound directly upon the core and rotated with it. If it were not for mechanical considerations, however, only the armature conductors would need to be rotated; the core could remain stationary.

ARMATURE REACTIONS.

25. When the current is flowing through the armature conductors, it produces several effects upon the magnetic field; and the field, in return, reacts upon the current. These effects will be considered before describing the typical forms of dynamos.

Consider the case of a single conductor in which a current is flowing from a voltaic battery or a continuous-current dynamo, and a magnet. It has been shown that a magnet and a conductor conveying an electric current exert a mutual force upon each other; or, in other words, each tends to produce motion in the other. In the case of a compass placed over or under a conductor conveying a current, if the magnetic needle be held rigidly and the conductor be allowed to swing freely in a horizontal plane, it would tend to place itself at right angles to the length of the needle. In general, *when a conductor conveying an electric current is placed in a magnetic field, the conductor will tend to move in a definite direction and with a certain force, depending*

upon the strength and direction of the current, and upon the direction and density of the lines of force in that field.

Imagine that a conductor conveying an electric current is placed across a uniform magnetic field, and that it lies in a position at right angles to the lines of force. For example, the diagram in Fig. 31 represents a cross-sectional view of a uniform magnetic field, the dots representing the ends of the lines of force and the heavy line a conductor conveying a current. The direction of the lines of force is assumed to be downwards, that is, piercing the paper; or, in other words, the observer is looking along the lines of force toward the face of a south magnetic pole. The lines of force along the conductor from the top to the bottom of the magnetic field act upon the current in the conductor with equal intensities, and all tend to move the conductor in the same direction. This action, if the magnetic field is uniform, is similar to that of a uniformly distributed load upon a beam tending to move or bend it.

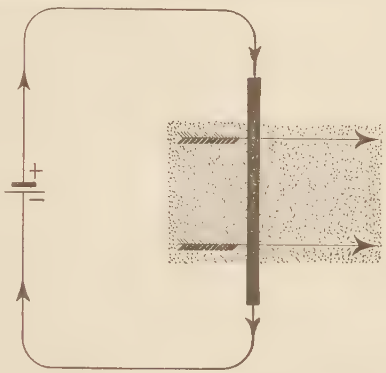


FIG. 31.

The motion imparted to the conductor is perpendicular to the lines of force, and also perpendicular to the flow of current in the conductor. To fulfil these conditions, therefore, the conductor in Fig. 31 must tend to move bodily either to the right or left across the field; in which of these two directions it moves depends upon the relative direction of the lines of force with the direction of the current in the conductor. In this case, if the direction of the lines is downwards, piercing the paper, and the current flows *from* the top *to* to the bottom of the diagram, as indicated by the small arrowheads, the conductor will tend to move from the left to the right in the direction in which the two large

arrows are pointing. If the direction of the lines of force only is changed, the conductor will tend to move in the opposite direction, i. e., from the right to the left; or, if the direction of the current in the conductor only is reversed, the conductor will tend to move also from right to left across the field. But should both the direction of the lines of force and the direction of the current in the conductor be changed, the conductor would still tend to move from left to right.

26. There is a convenient thumb-and-finger rule for remembering the direction of motion imparted to a conductor conveying an electric current when placed in a magnetic field; it is similar to the rule for generated currents, with the exception that the *left hand* is used instead of the *right*.

Rule.—*Place thumb, forefinger, and middle finger of the left hand each at right angles to the other two; if the forefinger points in the direction of the lines of force and the middle finger points in the direction toward which the current flows, then the thumb will point in the direction of movement imparted to the conductor.*

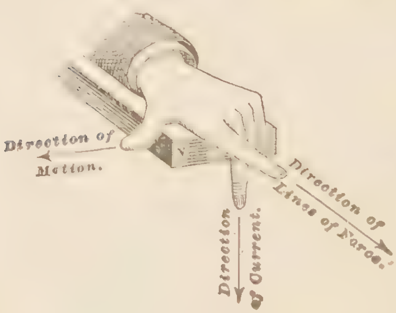


FIG. 32.

For example, in Fig. 32, if a vertical conductor in which a current is flowing downwards is placed in front of the north pole N of a magnet, it will tend to move in the direction as indicated by the thumb.

27. Comparing the rule in Art. **8** with that given above, it will be seen that the two appear to oppose each other; or, in other words, the current which flows in the former case, according to the latter rule tends to oppose the motion of the conductor and move it in the opposite direction. This

is exactly what takes place. When a conductor is moved across lines of force, an electromotive force is generated which tends to send a current in a definite direction; if the circuit is open and no current flows, it requires no force to move the conductor across the field; but if the circuit is closed and a current flows through the conductor, then the action of the lines of force on the current opposes the original motion and tends to stop or retard the conductor. The opposing force is proportional to the strength of current flowing in the conductor; that is, if a current of 10 amperes acts with a certain force, a current of 20 amperes will act with twice that force, and so forth. Hence, the stronger the current in the conductor, the greater will be the force necessary to keep the conductor moving in the original direction. The above explanation will be made clearer by the graphical illustration in Fig. 33. The diagram represents a cross-sectional view of a magnetic field, the direction of the lines of force being downwards, piercing the paper. If the conductor $c\,c'$ be moved across the field by some exterior motive power in the direction indicated by the arrows a, a, a current will flow through the circuit in the direction indicated by the small arrowheads. The length of the arrows a, a may also serve to represent the magnitude of the force that moves the conductor. As the current flows through the conductor, the lines of force immediately react upon it, producing a *counter* force which tends to stop the conductor and move it in the direction indicated by the arrows b, b. The counter force would never actually move the wire in the direction of the arrows b, b, but it exerts a dragging effect

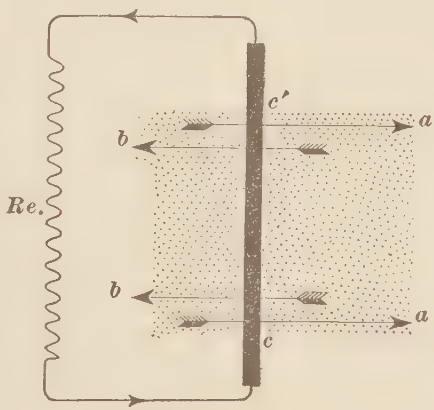


FIG. 33.

upon the conductor, which would reduce its speed and almost stop its motion if the exterior motive force were not increased. So long as the conductor is moved, the applied motive force is always larger than the counter force, as graphically represented by the relative lengths of the arrows.

28. The above principle explains the action of converting the mechanical energy into electrical energy in the dynamo. For example, suppose that an armature is rotated at a constant speed in a magnetic field by some exterior motive force, as, for instance, by a belt from an engine. If the armature is properly wound and connected to a commutator, an electromotive force is generated in the outside conductors on the core, causing a difference of potential between the brushes. If the brushes are not connected to an external circuit and no current is flowing through the armature, it requires no energy to rotate the armature, excepting a small amount to overcome the friction of the shaft in the bearings and the loss in the armature iron by eddy currents. By connecting the brushes to an external circuit, however, and allowing a current to flow through the armature, the conditions are altered. The lines of force react upon the current in the conductors, tending to rotate the core in an opposite direction and to retard its motion; the stronger the current, the greater will be the retarding effect. Hence, in order to keep the speed constant and to generate a constant E. M. F., more energy must be supplied to the pulley from the engine. This retarding effect of the current is known as the **counter torque** of a dynamo. The word torque, which will appear later in connection with the action of motors, means simply *turning* force.

It can be mathematically proved that the mechanical energy delivered to the armature from any exterior source is exactly equal to the electrical energy obtained from the armature plus the energy lost in mechanical friction, eddy currents in the iron, and other small losses, which will be described subsequently.

29. Besides producing a counter torque in the armature, the current tends to distort or crowd the lines of force from their original position in the magnetic field. This effect is termed **armature reaction,** and will be understood by investigating the magnetic effects of the current in the armature when the armature is removed from between the poles of the field magnets. In the diagram, Fig. 34, the current is flowing through the armature coil in the same direction as represented in Fig. 28. The current circulating around the armature coil in two directions acts as a magnetizing force upon the core and produces two electromagnets. According to the rule for magnetic polarity, the two magnets thus formed oppose each other at the two neutral spaces of the armature; that is, their like poles N, N' and S, S' tend to act in opposite directions at the neutral spaces. As previously explained, lines of force can never intersect each other, and will always produce consequent poles when acting in opposite directions at one place. Therefore, in this case, two consequent poles are formed in the core, one at each neutral space, as shown in the diagram. The polarity of the consequent poles, of course, depends upon the direction in which the coil is wound upon the core and the direction in which the current is generated. The same action occurs when the armature is rotated between the poles of a magnet and a current flows through the coil, although the conditions are somewhat altered. The lines of force from the magnet tend to pass through the core nearly at right angles to those produced by the current. The lines can never intersect,

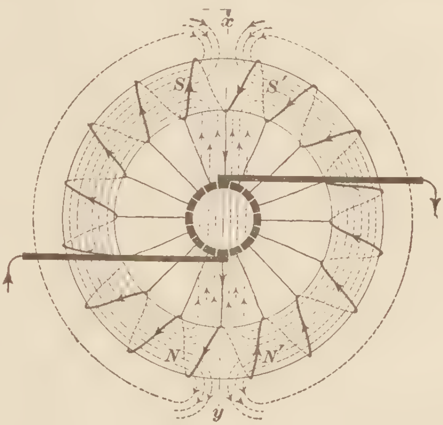


FIG. 34.

however, and they crowd and distort one another in order to coincide in direction. The lines that pass out from the north pole of the magnet tend to enter the core at the south consequent pole and to pass out from the core at the north consequent pole. At the same time, the south consequent pole is shifted toward the north pole of the magnet, and the north consequent pole toward the south pole of the magnet. The diagram in Fig. 35 represents the manner in which the magnetic field is distorted by the reaction of the armature current. In the case where the armature was

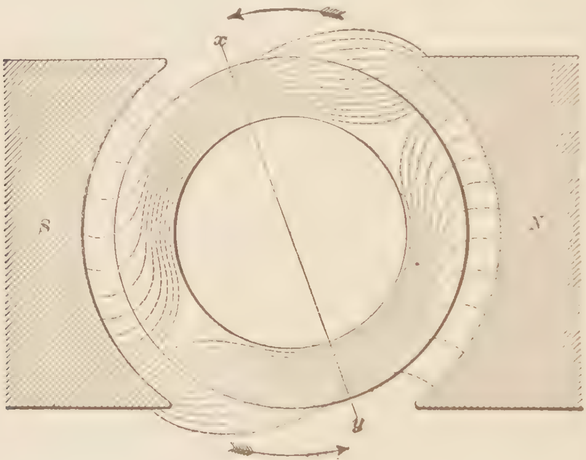


FIG. 35.

removed from the magnetic field, the consequent poles coincided with the neutral space; but when the armature is replaced, as in the diagram, the consequent poles are shifted backwards against the direction of rotation, and the neutral spaces are moved forwards in the opposite direction, as indicated by the imaginary diameter $x\,y$. As the positions of the neutral points on the commutator depend upon the positions of the neutral spaces on the core, they are also shifted forwards in the direction of rotation when the current flows through the armature; hence, the brushes must be moved

forwards in order to obtain the full E. M. F. generated in the coil. The stronger the current, the farther forwards the brushes should be shifted.

30. From the fact that in all dynamos of this character the relation of the lines of force, direction of rotation, and direction of current are constant, *the neutral spaces are always shifted forwards in the direction of rotation when the current becomes stronger*, no matter how the coil is wound upon the armature or in which direction the lines of force pass through the core.

These armature reactions are not confined entirely to the ring core, but are produced with the same effects in a drum-core armature, such as represented in Fig. 30. If the direction of the current is traced by the arrowheads upon the conductors, it will be seen that the current is flowing upwards along the face of the core in front of the north pole, as represented by the open circles, Fig. 36, and downwards in front of the south pole, as represented by the solid circles. The lines of force surrounding each conductor in which the current is flowing coincide with those around the adjacent conductors, forming a large number of long lines which pass through the core and produce consequent poles at the neutral spaces, as shown in Fig. 36. The direction of the lines of force around the conductors in which the current is flowing downwards corresponds with the movements of the

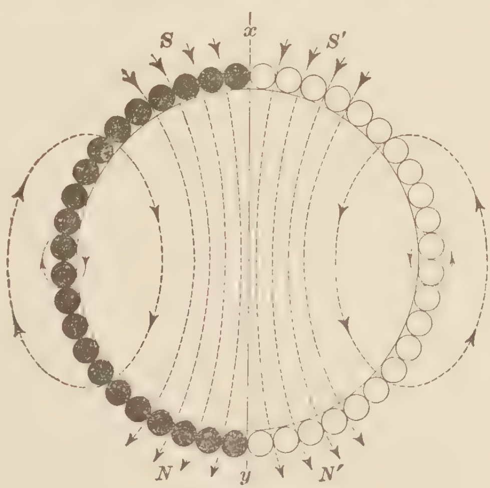


FIG. 36.

hands of a watch, while the direction of the lines around the other conductors is opposite. The lines from all conductors, however, coincide in direction in passing through the center of the core. When the armature is rotated between the poles of a magnet, the field is distorted and the neutral spaces shifted forwards in a manner similar to that described for the ring core.

31. Armature reactions not only distort the magnetic field, but also have a tendency to reduce the total number of lines of force from the magnet, and thereby diminish the E. M. F. generated in the armature. This effect, however, can be almost entirely eliminated by increasing the strength of the field, or, in other words, by increasing the number of lines of force passing through the core. This fact leads to the consideration of *field magnets*.

FIELD MAGNETS.

32. It has been previously stated that the magnetic field in all dynamos is produced from either a permanent magnet or an electromagnet. A dynamo of the first class is called a **magneto-machine.** Such machines are necessarily small on account of the difficulty of making large permanent magnets; in fact, the field in most magneto-machines is produced by several permanent magnets placed side by side. The magnets are usually of the U-shaped pattern, of hard steel, and with a recess bored out between the ends of the poles to admit the armature, as shown in the diagram, Fig. 37.

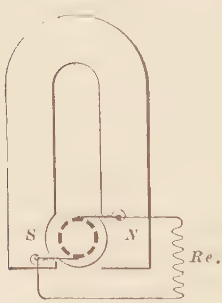


FIG. 37.

As the majority of magneto-machines are made for testing and signaling purposes where alternating currents can be used to advantage, the armature is wound with one large

coil of wire, and the two ends of the coil are connected to two separate collector rings, as shown in Fig. 38. The alternating current is obtained from two brushes, one rubbing against each collector ring. The brushes can bear upon the collector ring at any position relative to the coil and the

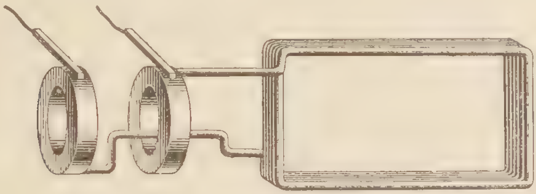


FIG. 38.

field magnets, since all parts of one collector ring are at the same potential in any instant. By comparing this coil with that in Fig. 13, it will be seen that the current obtained from the two brushes flows in two directions during every revolution.

33. In nearly all dynamos furnishing current for lamps, power, and other commercial purposes, the magnetic field is produced by an electromognet. This class of dynamos is divided into various types, depending upon the manner in which the current is obtained to excite the field magnets.

34. The first class of machines to be considered is termed a **separately excited dynamo**, from the fact that its field magnets are excited or magnetized by a current from some external source, as, for instance, a voltaic battery, or another continuous-current dynamo. The connections of a separately excited dynamo are represented in Fig. 39. The magnetizing coils are wound around the cores of a magnet and connected to the terminals of a voltaic battery *B*. The exciting current flows from the battery around the cores of the field magnet in such a

direction as to produce a closed magnetic circuit through the armature, and has no connection whatever with the current obtained from the brushes by rotating the armature. If the strength of the exciting current is not changed, the difference of potential between the brushes of the dynamo when the armature is rotated at a uniform speed remains constant so long as the external circuit is open; but when the external circuit is closed, the difference of potential gradually diminishes as the strength of current increases, owing to the internal resistance of the armature conductors and the reactions of the armature current on the field.

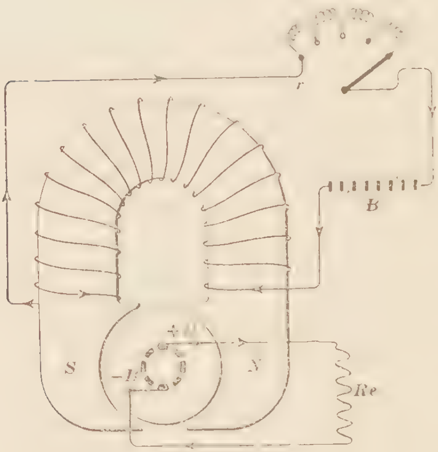


FIG. 39

35. The **magnetizing force** is that which produces the lines of force in the magnet. Its strength is proportional to the strength of current flowing and to the number of coils or complete turns around which the current circulates. The total number of turns multiplied by the strength of the current in amperes will give the magnetizing force in **ampere-turns.** It has been proved that 10 amperes circulating around 20 turns exert precisely the same magnetizing force as 1 ampere circulating around 200 turns, or as 200 amperes circulating around 1 turn. In each of these cases, the magnetizing force is 200 *ampere-turns.* But the number of lines of force produced in an electromagnet is not directly proportional to the magnetizing force in *ampere-turns.* The strength of the magnet in lines of force depends upon the permeability of the magnetic substances used in

the core. The permeability varies greatly in different magnetic substances, depending upon both the physical condition and the chemical composition of the substance. In general, *wrought iron*, *soft sheet iron*, and *steel* have greater permeability than cast iron, and, whenever available, should be used in field magnets in preference. The permeability, however, of all magnetic substances changes with every stage of magnetization. In all kinds of magnetic substances, the permeability decreases when the magnetism is increased beyond a certain limit. This tendency of the substance to become less permeable is called **magnetic saturation**; that is, the substance becomes *saturated* with lines of force and cannot hold any more. A limit is never reached where actual saturation takes place, but there is a limit beyond which it becomes impracticable to magnetize the substance. The practical saturation in wrought iron, soft sheet iron, and cast steel is when there are between 120,000 and 130,000 lines of force per sq. in. of sectional area of the iron, measured on a plane at right angles to the lines of force in the magnet. In gray cast iron, the practical saturation limit is from 60,000 to 70,000 lines of force per sq. in. Hence, when these limits are exceeded, it requires an enormous increase in the *ampere-turns* to produce a slight change in the number of lines of force in the magnet. In general, however, the field magnets of dynamos are designed with the density of the lines of force below the saturation limits, and it is safe to assume that any change in the strength of the current circulating around the magnetizing coils produces a corresponding change in the number of lines of force passing through the magnetic circuit. Consequently, if the strength of the current in the field coils of a *separately excited* dynamo is increased as the current in the armature becomes stronger, the E. M. F. obtained from the brushes will remain practically constant. This is usually accomplished by inserting an adjustable resistance box, or field rheostat r, in series with the battery and field coils, and decreasing the resistance as the difference of potential between the brushes tends to drop.

36. The second class of machines with an electromagnet is termed a **self-exciting shunt dynamo,** or simply a **shunt dynamo,** from the fact that the exciting current for the field magnet is furnished by the dynamo itself, the field coils being connected in *shunt* with the external circuit from the brushes. In Fig. 40, one terminal of the magnetizing coil is connected to the positive brush, and the other to a binding post on the field rheostat *r*; the negative brush is connected to the arm of the field rheostat. If the resistance of the rheostat is neglected or cut out, it will be seen that the total difference of potential exists between the terminals

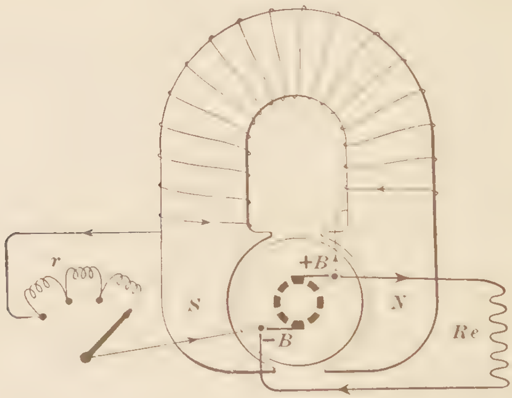


FIG. 40.

of the magnetizing coils when the dynamo is generating its maximum E. M. F. The magnetizing coils of a shunt dynamo, however, consist of a large number of turns of fine copper wire, thus making the resistance large in comparison with the difference of potential between the field terminals. In well-designed dynamos the resistance of the shunt coil is large enough to allow not more than about 5% of the total current of the dynamo to pass through the field coils; for, according to Ohm's law, the strength of current in amperes circulating around the field coils is equal to the difference of potential in volts between the brushes,

divided by the resistance in ohms in the field coil, neglecting the resistance of the rheostat. For example, suppose that the difference of potential between the brushes of a shunt dynamo is 500 volts when a current of 10 amperes is flowing from the armature. If 5% of this current is required to excite the field magnets, the strength of current circulating around the field coils is $10 \times .05 = .5$ ampere; and if E_e is the E. M. F. at the brushes, C_s is the current in the shunt field, and R_s is the resistance of the shunt field, then, according to Ohm's law, $R_s = \frac{E_e}{C_s} = \frac{500}{.5} = 1{,}000$ ohms.

37. When a shunt dynamo is rotated at a constant speed, an appreciable length of time elapses before the armature generates a maximum E. M. F. after the field circuit is closed, and in some cases a self-exciting dynamo will generate no E. M. F. until after it has been once separately excited. The starting of a dynamo to generate an E. M. F. is termed **picking-up**, or **building-up.** If the field circuit of a dynamo is open so that no current flows through the magnetizing coil, the armature will generate no E. M. F. when rotated, provided the field magnets are not permanent magnets; consequently, when the field circuit is closed on a shunt dynamo, no current will flow through the magnetizing coils, because there is no difference of potential between their terminals. But nearly all magnetic substances become permanent magnets in a slight degree after once being magnetized.

This permanent magnetism is called **residual magnetism,** since it *resides* in the metal after the magnetizing force has been removed. In general, soft iron and annealed steel retain only a small amount of magnetism, and in some cases the residual magnetism is imperceptible. Chilled iron and hardened steel retain residual magnetism in large quantities. Artificial or permanent magnets are made by placing a piece of hardened steel in a dense magnetic field or in contact with another magnet. Lodestone is the result of a natural residual magnetism. Iron and its alloys will also

become slightly magnetized in the process of refining and working.

From these facts it will be seen that the cases where field magnets do not exhibit some residual magnetism are exceedingly rare. The armature conductors when cutting the lines of force of the residual magnetism generate a small E. M. F., and this E. M. F., in turn, causes a feeble current to circulate around the magnetizing coils when the field circuit is closed. The residual magnetism is, therefore, reenforced by the magnetizing effect of the current, which is followed by an increase in the E. M. F. generated, and that, in turn, by a stronger current in the field. These actions and reactions continue until a limit is reached where the fields become saturated with magnetism, and the number of lines do not increase at such a rapid rate; finally, both the E. M. F. and the current in the field become constant.

38. The difference of potential between the brushes of shunt dynamos gradually decreases as the current from the armature becomes stronger, on account of the internal resistance of the armature conductors and the reactions of the current on the field. The effect is even more marked than in separately excited dynamos, because a decrease in the difference of potential between the brushes causes a corresponding decrease on the field terminals, thereby weakening the current in the magnetizing coils. In order to compensate for the decrease in the E. M. F., a field rheostat *r* of comparatively high resistance is connected in the field circuit, and so adjusted that when no current is flowing in the external circuit only enough current flows through the field to produce the normal difference of potential between the brushes; this normal difference of potential between the brushes is kept constant as the load increases by gradually cutting out, or short-circuiting, the resistance coils of the rheostat.

NOTE.—The word *load* as used above is a common expression for *current* in dynamos generating a constant potential, and the student should become familiar with its use.

39. The third class of machines whose field magnets are excited by an electric current are termed **self-exciting series dynamos,** or simply **series dynamos.** The magnetizing coils of a series dynamo are connected directly in *series* with the external circuit; that is, all the current from the armature circulates around the magnetizing coils and flows through the external circuit. The connections of a *series* dynamo are shown in Fig. 41. The current starts from the positive brush $+B$, circulates around the external circuit Re, from thence through the magnetizing coils back to the negative brush $-B$. The action of a series dynamo differs widely from that of a shunt dynamo. In the first place, no E. M. F. is generated in the armature unless the external circuit is closed and a current flows from the brushes, that is, neglecting the small E. M. F. generated by the residual magnetism. In the second place, the difference of potential between the brushes depends upon the strength of current flowing from the armature. The E. M. F., however, is not directly proportional to the strength of the current unless the internal resistance and reactions of the armature are negligible. Compared with the coils on a shunt dynamo, the magnetizing coils of a series dynamo are made of a few turns of a large conductor. This is necessary, because the coils usually are required to carry the total current from the armature; the conductor is made large to carry the current without heating, and only a few turns are used to secure the proper degree of magnetization, since that is proportional to the *ampere-turns.*

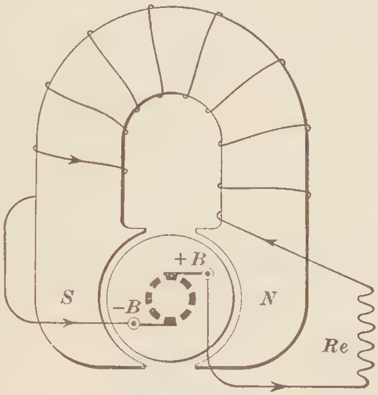


FIG. 41.

40. The E. M. F. of a series dynamo may be regulated in three different ways, viz.: (1) By controlling the strength

of current in the external circuit as previously described; (2) by *short-circuiting*, or *cutting out*, part of the magnetizing coils; and (3) by *shunting* part of the current around the magnetizing coils.

The second of the above methods of regulating the E. M. F. will be understood from the diagram in Fig. 42. *S F* represents the magnetizing coils. *A* is a contact arm which travels in either direction along the line *x y*, one end making contact with the ends *a*, *b*, *c*, *d*, etc. of the series field, and the other being always connected to the external circuit *Re*. As the arm is moved toward *x*, the turns between it and *k* are cut out of circuit; that is, the current from the armature circulates around only those coils between the arm and *a*; if the strength of the current remains constant, the magnetizing force is thereby reduced. On the contrary, when the arm is moved toward *y*, additional turns are connected in circuit, and the magnetizing force is increased.

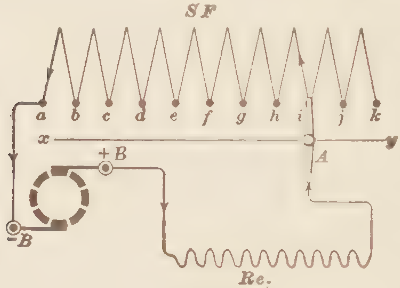


FIG. 42.

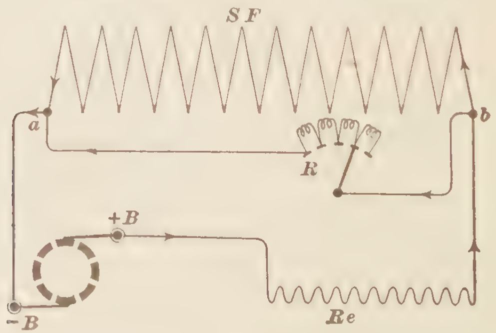


FIG. 43.

41. The third method of regulating the E. M. F. of a series dynamo changes the strength of the magnetizing current instead of varying the number of turns in the coil.

This effect is accomplished by connecting a resistance *R*, Fig. 43, in parallel or shunt with the series field coils *S F*, the current dividing between the two circuits inversely proportional to their separate resistances. Consequently, to increase the magnetizing force on the field magnets, the resistance *R* of the shunt circuit is increased, and vice versa. The total current from the armature is made to pass through the magnetizing coils by opening the shunt circuit entirely.

42. In the dynamo previously described, the regulation of the E. M. F. is not automatic; it is accomplished by a mechanical movement of an arm or contact. This movement is sometimes imparted by a magnet controlled by the current from the armature, but more often the E. M. F. is automatically regulated in the dynamo itself by a combination of the *shunt* and *series* magnetizing coils. Such machines are termed **compound,** or **shunt-and-series,** dynamos. In

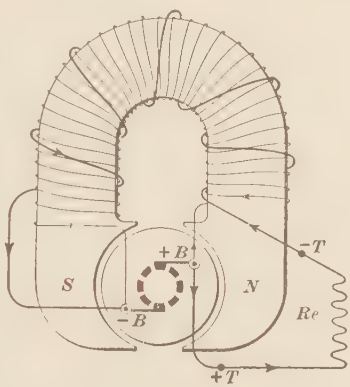
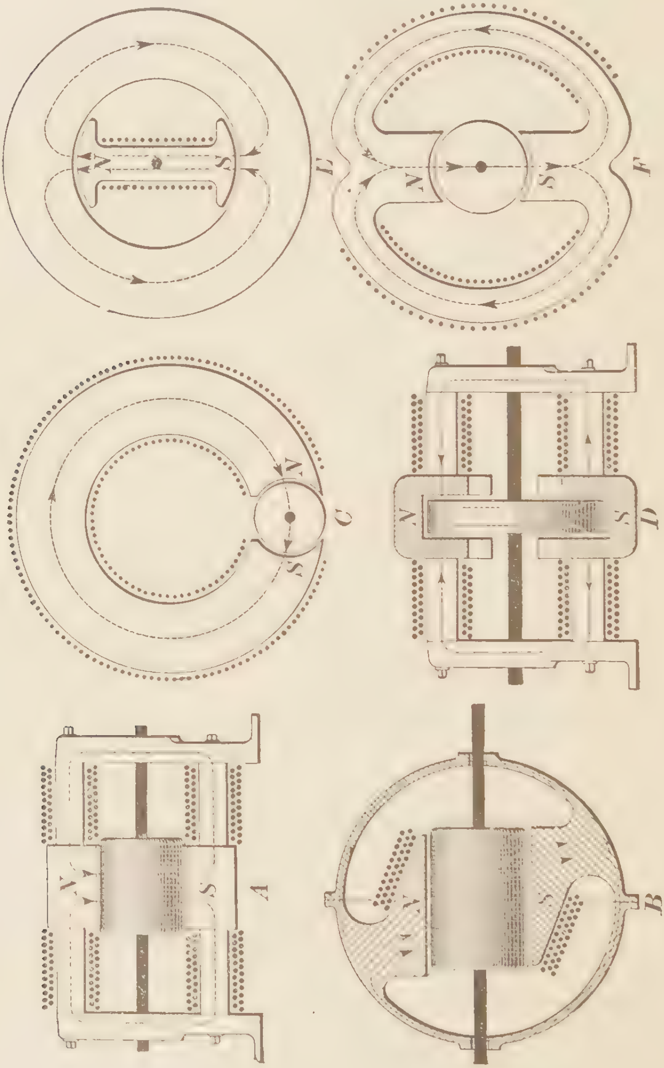


FIG. 44.

Fig. 44, the shunt coils consist of a large number of turns of fine insulated wire wound upon the core of the magnet. The series coils, consisting of a few turns of large insulated wire, are wound over the shunt coils. The main part of the current from the armature flows from the positive brush $+B$, through the external circuit *Re*, thence through the series coils to the negative brush $-B$. The two terminals of the shunt coils are connected to the two brushes $+B$ and $-B$, respectively. But the series and shunt coils are so wound that the currents in both circulate around the core of the magnet in the same direction when connected, as shown in the diagram. The action of both currents, therefore, is to produce the same polarity in the magnet,

the shunt current being reenforced by the series current. When the dynamo is not loaded, that is, when no current is



flowing in the external circuit, and the armature is rotated at normal speed, the normal E. M. F. is generated in the

armature due to the magnetic field produced by the shunt coils alone. Upon closing the external circuit, however, the difference of potential between the brushes *tends* to

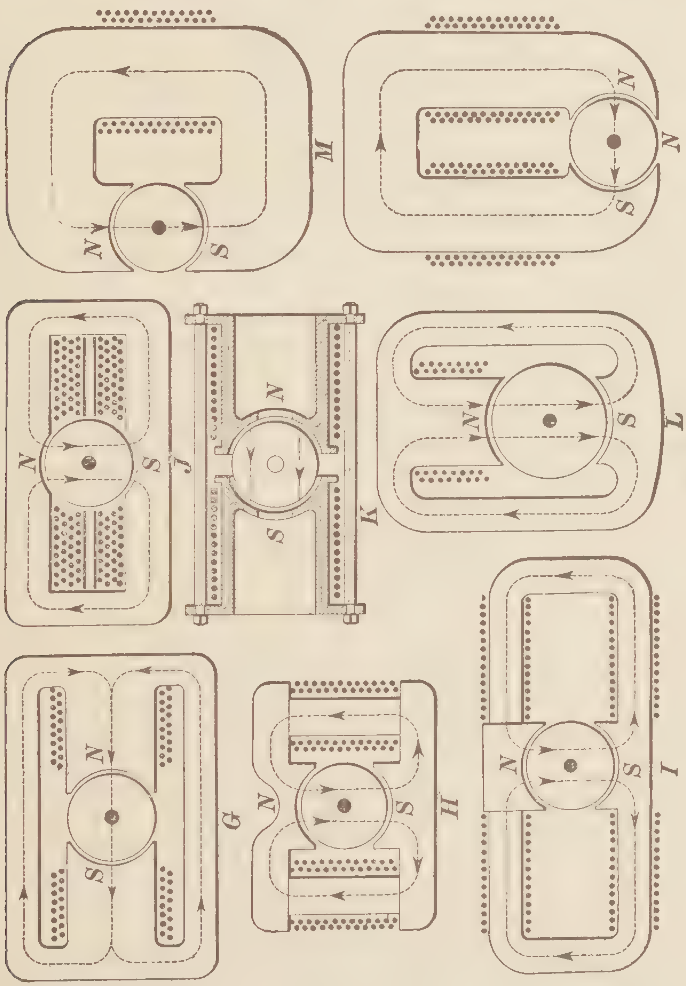


FIG. 45.

decrease, and would continue to decrease, as previously described in a simple shunt machine, if the series coils were neglected. The current circulating through these, however,

reenforces the magnetizing force of the shunt coils, and immediately increases the number of lines of force in the field, which, in turn, raise the difference of potential between the brushes to normal. These actions are produced simultaneously, and, to all appearances, the difference of potential between the brushes remains normal for all changes of load in the external circuit. This method of regulating the E. M. F. of a dynamo is called **compounding.** The **terminals** of a dynamo are the binding posts to which the external circuit is connected; in a series, or compound, dynamo one terminal is attached to the outside end of the series coils, as $-T$ in Fig. 44, and the other terminal is connected directly to the brush, as represented by $+T$ in the figure. It is desirable in a great many cases to **over-compound** a dynamo, or, in other words, to wind a sufficient number of turns on the series coils so as to increase the difference of potential between the terminals of a dynamo above normal when the load increases. The expression **per cent. over-compound** means that the difference of potential between the terminals increases a given per cent. of the normal when the load is at a maximum. For example, supposing the normal voltage of a dynamo is 500 volts and it is 10% over-compound at full load; the difference of potential between the terminals of the machine at full load is, therefore, $500 + (500 \times .10) = 550$ volts.

In some cases it is an advantage to connect the shunt field outside the series coils; that is, in Fig. 44, to connect the negative end of the shunt coil to the negative terminal $-T$, instead of being connected to the negative brush $-B$. This connection is seldom used in practice.

TYPES OF BIPOLAR FIELD MAGNETS.

43. The various types of field magnets for dynamos in which the armature revolves between only one pair of poles are shown in Fig. 45. It is customary to speak of such machines as **bipolar dynamos**, from the fact that only one

pair of poles is presented to the armature. The broken lines and arrowheads in each of the separate cuts represent the paths of the lines of force which must pass lengthwise through the coils from the north pole to the south pole. The black dots indicate a cross-section through the wires which form the coils.

Field poles are distinguished as follows with respect to the coils producing them: (*a*) **salient poles**; (*b*) **consequent poles.**

In all cases where a single coil is used, or where, if two coils are used, they are wound so as to produce unlike poles at their free ends, the poles are called salient poles. When two coils are used and wound so as to make their adjacent poles similar, the resultant poles are called consequent poles.

Referring to Fig. 45, salient poles exist in fields *B*, *C*, *E*, *G*, *J*, *K*, *L*, *M*, *N*, and consequent poles in *A*, *D*, *F*, *H*, *I*. The adjacent coils in *A*, Fig. 45, have their adjacent poles at *N* and *S* similar. Were these poles opposite, the magnetic flux would circulate around the magnets without passing through the armature.

TYPES OF DYNAMOS.

44. Dynamos are divided into three general types, depending on the character of their currents. These three types are:

1. **Constant-potential dynamos,** in which the E. M. F. remains constant and the strength of current (continuous) changes with the load or external resistance.

2. **Constant-current dynamos,** in which the strength of current (continuous and pulsating) remains constant and the E. M. F. changes with the load.

3. **Alternating-current dynamos,** the current from which alternates or reverses direction with great rapidity

and whose E. M. F. is constant. In ordinary alternating-current dynamos, the reversals average generally either 7,200 or 16,000 per minute.

NOTE.—A dynamo which generates current for power purposes has been conventionally termed a *generator*, to distinguish it from a machine for lighting.

CONSTANT-POTENTIAL DYNAMOS AND GENERATORS.

45. The foregoing articles have demonstrated the principle and regulation of constant-potential dynamos, but only one form has been considered, namely, a dynamo in which a ring or drum armature is rotated between only one pair of poles from a U-shaped magnet. Theoretically, however, constant-potential dynamos can be built with one armature revolving between any number of pairs of poles, although in practice eight pairs of poles are seldom exceeded, except in machines for large output and slow speed. Machines having more than one pair of poles are called **multipolar dynamos.**

In multipolar dynamos the pole pieces and field cores are fastened into one magnetic yoke, more or less circular in shape, as shown in Fig. 46, which represents the magnetic circuits of a four-pole dynamo. A magnetizing coil is wound upon each field core, and the four coils are connected in series in such a manner that when a current circulates around the coil, it produces first a north pole and then a south pole. The lines of force from each field core divide into two magnetic circuits in

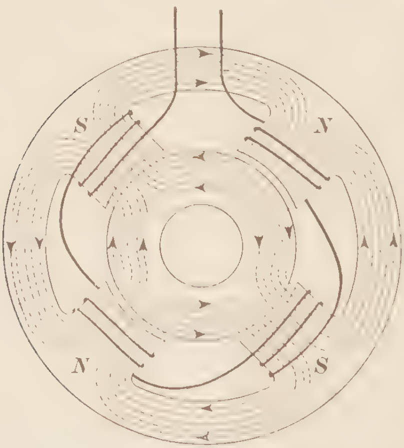


FIG. 46.

the yoke and armature, as represented in the diagram. Their density is practically uniform, however, where they pass from the north pole into the armature core, or from the armature core into the south pole. In nearly all multi-polar dynamos this same principle of polarity is applied, that is, every *other* pole is of like polarity, and lines of force from each core divide into two magnetic circuits, in the armature and in the field yoke.

46. The process of generating an E. M. F. is similar to that in bipolar machines, but there are some points which should be understood. Consider first the case of a ring core

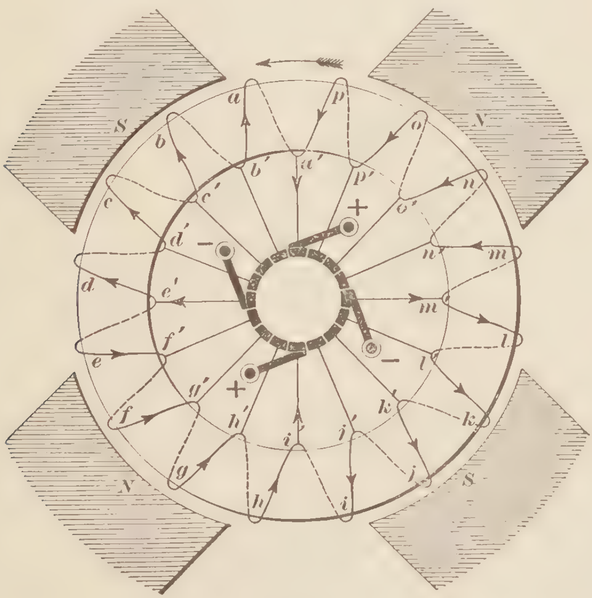


FIG. 47.

with a closed-coil winding as shown in the diagram, Fig. 47. If the armature is rotated in the direction of the large arrow, the E. M. F. generated in the conductors in front of the south poles will tend to act downwards along the face of the pole, while that generated in front of the north pole will

tend to act upwards. By tracing out, by aid of the small arrowheads on the conductors, the direction in which the E. M. F. acts, it will be seen that there are four points where the E. M. F. acts in opposite directions. The action of the electromotive forces is to meet at a' and i' and to divide at e' and m'. The segments connected to a' and i' have the same potential and form two *positive* neutral points of the commutator; the segments connected to e' and m' have the same potential and form two neutral points of the commutator. Hence, four brushes are necessary—two positive and two negative. The current is obtained from the armature by connecting the two positive brushes in parallel to one terminal of the external circuit and the two negative brushes to the other terminal, as shown in Fig. 48. The currents from the positive brushes unite to form the current in the external circuit and divide again between the negative brushes. The current in the armature is divided into four circuits in parallel instead of two, as in bipolar dynamos, and the maximum E. M. F. that is obtainable from the brushes is equal to that generated by the active conductors in one of the circuits only. For example, the difference of potential between the positive and negative brushes in Fig. 47, when no current is flowing, is equal to the E. M. F. generated in one-quarter of the outside wires on the core; or, in other words, the total E. M. F. of the armature is proportional to the number of outside wires connected in series between brushes of opposite polarity.

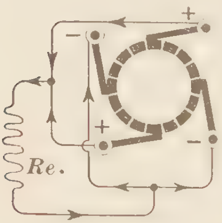


FIG. 48.

The current in a ring armature wound and connected in this manner, if placed in a field magnet of six poles, would divide into six circuits in parallel; if the armature is placed in a field magnet of eight poles, the current would divide into eight circuits in parallel, and so on. An armature winding of this character is called a **parallel, or multiple, winding,** since the current divides into as many circuits in parallel as there are poles in the field magnet.

47. It is possible, however, to connect and group the conductors in an armature for a multipolar dynamo so that

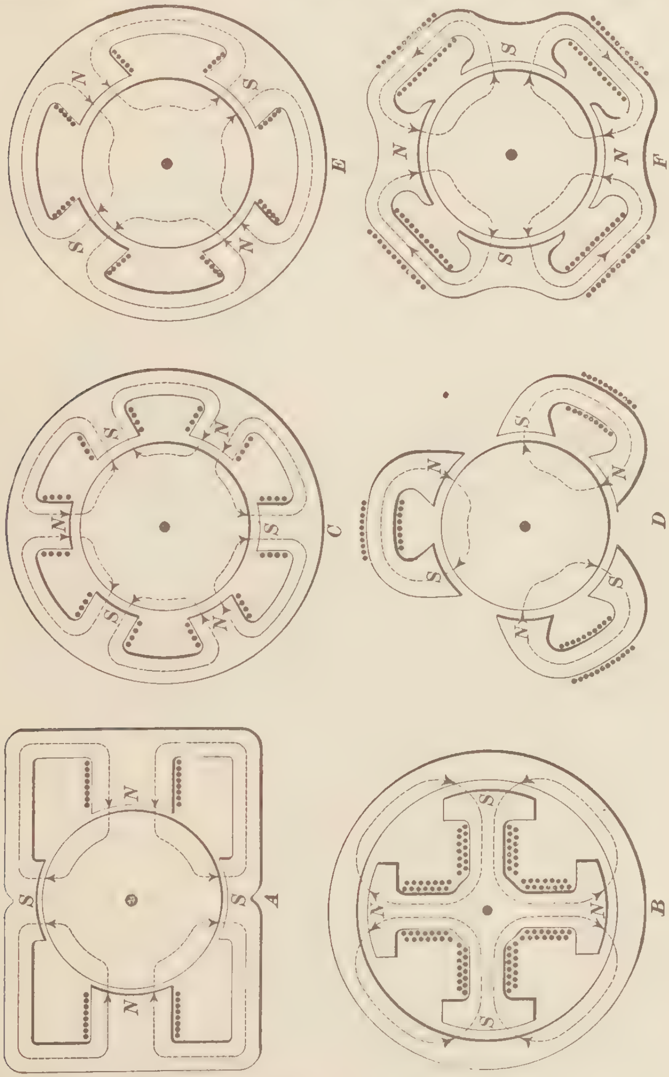


FIG. 49.

the current divides into two circuits only, making the number of active conductors in series equal to one-half the total

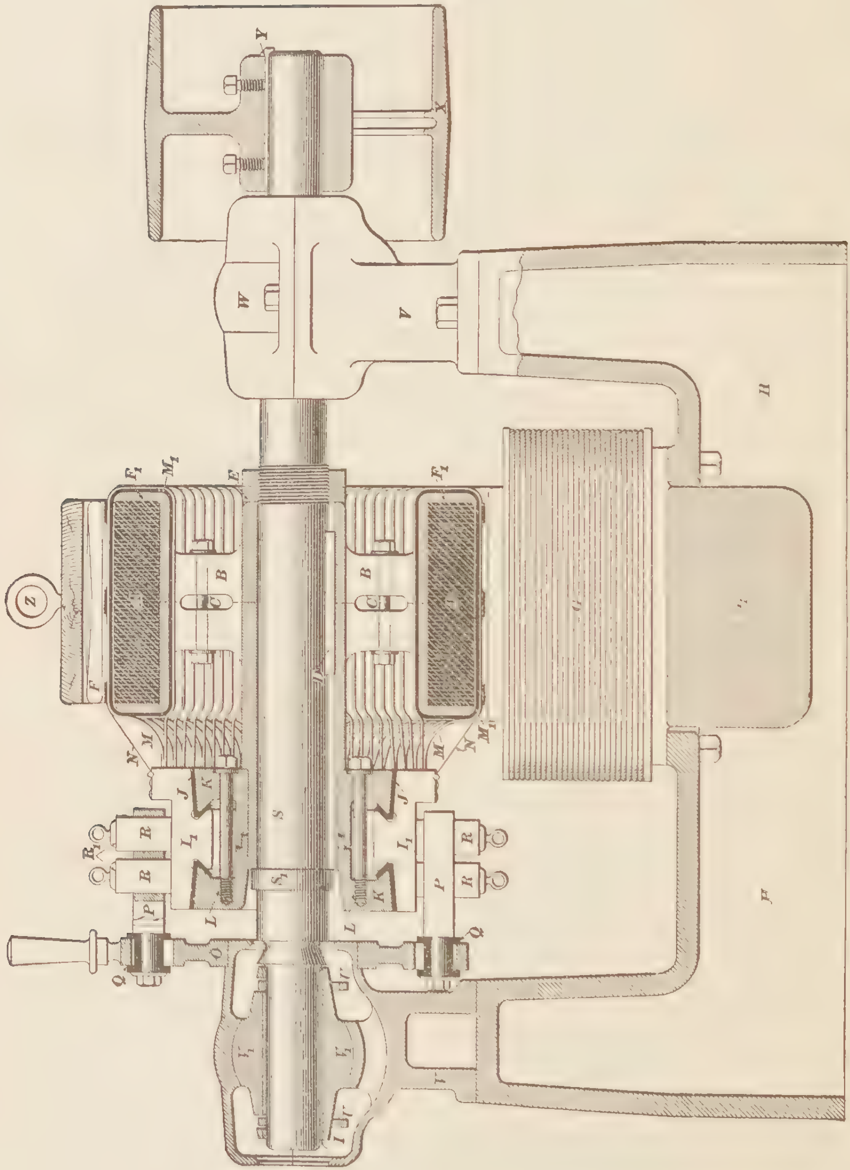


FIG. 50.

number of outside wires on the core. This armature winding is termed a *series winding*, since one-half of the total outside wires is the largest possible number that can be connected in series and produce a continuous current.

There are many different methods of connecting and winding armatures for generating a continuous current, the method used depending upon the character of the current and E. M. F. desired. Drum windings as well as ring windings are connected in a variety of ways for multipolar and bipolar dynamos, but the principle of commutation and generation of E. M. F. does not differ from that previously described; the E. M. F. is always proportional to the number of outside or active wires connected in series.

48. The regulation of multipolar dynamos for constant potential is accomplished by the changing of the strength of the magnetizing force, as in the bipolar machines. In a compound dynamo, the series coils are wound on each field core and all connected together in parallel or series, whichever is more expedient.

49. Types of Multipolar Field Magnets.—The various types of multipolar field magnets are shown in Fig. 49. Consequent and salient poles are used as in bipolar field magnets, but the type generally employed has salient poles alone, as in *C* and *E*. *A* embodies both consequent and salient poles. In *B* the field magnet is surrounded by the armature and is known as an *internal-pole* dynamo. The armature in all cases is that part of a dynamo in which the current is generated. Each type of field magnet in the above figure has its own special advantages, but all represent good design.

50. Mechanical Construction.—Heretofore, only the principles of a dynamo have been considered; its mechanical construction in detail depends upon the requirements of the machine and upon the originality and taste of the designer. A few general remarks, however, on the construction of the principal parts of the machine are necessary

to give the student a clear conception of a complete dynamo ready for operating.

The mechanical construction of a typical bipolar dynamo is shown in Fig. 50, which is a vertical section taken along the center of the armature shaft. The parts of the machine shown in the figure are lettered, and the names of the parts corresponding to the letters are as follows:

A = Armature core, which may be either punchings from sheet iron or built up of fine annealed iron wire.
B = Armature spider for connecting core to shaft.
C = Armature spider bolts.
D = Armature key for fastening spider to shaft.
E = Armature locknut.
F = Pole piece.
G_1 = Magnetic yoke.
G = Magnetizing or field coil.
H = Frame.
I_1 = Commutator bars or segments.
J = Commutator insulation.
K = Commutator shell or body, and rings for holding commutator segments in place.
L = Bolt for clamping commutator frame.
M = Armature leads, connecting armature winding to commutator.
N = Armature dressing or covering.
O = Rocker-arm or brush-holder yoke.
P = Brush holder.
Q = Insulating bushings.
R = Carbon brushes.
R_1 = Carbon-brush hammers.
S = Shaft.
T = Bearing or brass.
U = Oil rings.
V = Standard.
W = Cap for standard.
(Complete outfit called pillow-block.)
X = Pulley.
Y = Key for pulley.
Z = Eyebolt.

51. Frame.—The frame is made up of two castings; the upper one forms the magnetic yoke *G*, and pole pieces *F*, and is bolted to the lower one *H*, which forms the base and is extended on either side to support the standards *V*, *V*. The pole pieces are bored out to admit the armature core when wound; the standards are bolted to the base casting and are so adjusted as to allow the armature core to revolve centrally between the pole pieces. The magnetizing or field coils *G*, only one of which is shown in this cut, are wound on separate bobbins or spools, and one is slipped over each pole piece.

52. Armature.—As generally used, the word **armature** includes the wound core and commutator mounted on the shaft ready for operating. In Fig. 50, the armature spider *B* is made in halves; each half is provided with flanges F_1 at the ends to hold the disks or sheets of iron *A* in place. The disks are punched in circular rings from thin sheet iron annealed, and a large number are slipped over each half of the spider, which is then bolted together by long spider bolts *C* as shown. The spider usually has three or four arms joining the flanges to the hub, the armature conductors on the inside of the ring, in case of ring winding, being wound between the arms. The hub of the spider is bored out to slip over a portion of the shaft *S*; it rests against a turned shoulder S_{11}, and is held in this position by the armature nut *E*. The spider and core are made to revolve with the shaft by the aid of a key or feather *D*, fitted into the spider hub and into the shaft. The core and spider are insulated by mica, cloth, paper, etc., M_{11}, and the armature conductors are wound on them in the manner previously described, with armature leads properly connected to the winding at suitable places. After the core has been wound and the leads connected to the commutator, the winding is sometimes covered or dressed with cloth of suitable texture to prevent flying particles and dust injuring or short-circuiting the coils. The armature leads should be made of a flexible conductor or cable, insulated from one another with

cotton or rubber tape; an electrical contact of two leads will short-circuit and burn out the intervening coil. It is sometimes the practice to use the armature conductors themselves for leads by looping the conductor and connecting the end of the loop to the commutator. This is bad practice, however, and, except for small dynamos, ought not to be followed. A large, solid copper wire is liable to become crystallized by the repeated vibration of the machine and will eventually give way.

53. Commutator.—Every maker of dynamos has a special design of commutator, but all embody the same general construction. Fig. 51 shows two enlarged views of a commutator such as is shown in place in Fig. 50. It will be noticed that the segments are broader on the outside of the commutator than near the center, thus providing for an equal thickness of insulation between all parts of adjacent bars. A portion *a* of each segment projects above the general level of the commutator surface, and is provided with a slot into which the armature leads are securely fastened by screws *s*, *s*, as shown at *l*. Sometimes the leads are soldered to the segments. The method of clamping and securely holding the segments is shown in the lower view. The commutator shell, it will be seen, consists of two rings $c\,c$ and $c_1\,c_1$, clamped together by bolts *b*, *b*. The notches *n* in the segments fit over corresponding projections on the rings, and as the bolts are tightened the segments are drawn firmly against the insulation which separates them. The commutator shell is usually made of brass, sometimes of cast iron. This shell is, of course, thoroughly insulated from the commutator segments. A key is fitted into the commutator shell and shaft to cause the commutator to turn with the shaft. The armature leads from the winding are soldered or screwed to ears or clips extending from each commutator bar, as shown by the cross-sectional view.

54. Brushes and Brush Holders.—In the cut of the machine in Fig. 50, the brushes shown are made of carbon and rub against the segments of the commutator radially,

the pressure being regulated by a spring which is attached to a hammer pressing on top of the carbons. The carbons slide in slots in the brush holders, fitting snugly, with but little play or lost motion sideways. Both brush holders are provided with studs which pass through holes in the rocker-

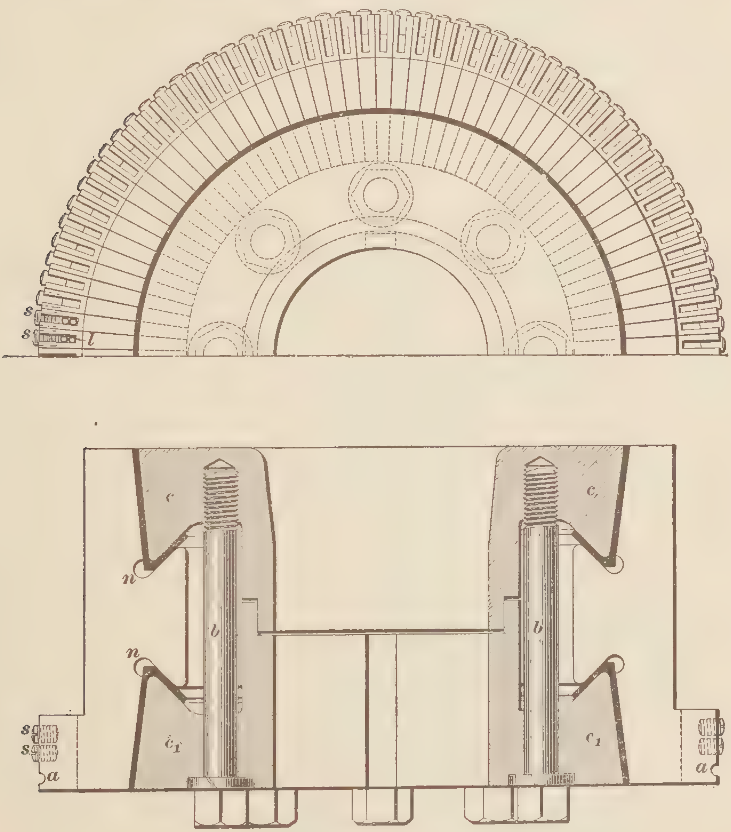


FIG. 51.

arm, each stud being insulated from the arm by insulating bushings, as shown in the cross-sectional view. The rocker-arm is fitted over the journal-box, and can be rocked or rotated to change the position of the brushes on the commutator as the position of the neutral points changes when

the load is varied. This action is usually accomplished by a handle attached to the rocker-arm; and a thumbscrew or set-screw is provided to hold the rocker-arm in position when properly adjusted. The current is taken from the brushes by a cable or flexible conductor connected to the brush holder, generally by the use of a small cable clip surrounding the stud. On some kinds of dynamos it is customary to use copper brushes; that is, brushes made either of copper leaves, strips, wires, or gauze. Such brushes are built in a great variety of ways, and on constant-potential machines are generally used where the E. M. F. does not exceed 125 volts.

55. Journals or Bearings.—The armatures of most dynamos are generally driven at a high speed compared with the average rotating machinery, and hence it is important that the journals or bearings should be of the best design possible. In the dynamo shown in Fig. 50 the bearings are called **self-alining** boxes; that is, the linings are allowed to find their own alinement with the shaft. This is accomplished by turning a spherical surface l_1 around the center of the lining and turning the cap and standard to match, as shown in the cross-sectional view. The linings l in such a bearing are usually made of some composition metal, as bronze or gun-metal, for small machines; on large machines the linings are made of cast iron covered on the inside with babbitt metal.

The best practice in lubricating high-speed journals in dynamos is to make the bearings *self-oiling* or *self-lubricating;* that is, to design the bearings with a reservoir of oil below the journal, using some device to carry the oil from the reservoirs to the top of the journal, from whence it flows around the journals and drops back into the reservoirs again. This method produces a constant circulation of oil around the journals and allows the oil to be used over and over again.

A good method of automatically oiling or lubricating bearings on journals is shown in the cross-sectional view in

Fig. 50. Two slots are cut across the top of each lining, permitting two circular *oil rings U* to rest upon the journals of the shaft; the diameters of the rings are made large in comparison with the diameter of the shaft, and their lower parts dip into the reservoirs of oil. When the shaft is rotated, the friction between it and the inside of the oil rings causes the latter to revolve, thus carrying the oil which adheres to the bottom part of the rings to the top of the journal, where it finds its way between the linings and the shaft.

In general, any freely lubricated journals can be used in dynamos or generators.

56. Driving Mechanism.—The armatures of nearly all dynamos are driven in one of the following ways: (1) By using a flat belt passing over a pulley on the armature shaft. (2) By using several ropes, side by side, running in a grooved pulley. (3) By connecting the armature directly to the crank-shaft or shaft of the driving machine, which, in most cases, consists of a steam engine, steam turbine, or water-wheel. In any of the above methods, the driving mechanism should be amply capable of transmitting the total output of the dynamo with a suitable factor of safety.

57. A perspective view of the bipolar dynamo just described is shown in Fig. 52. In the figure the machine is represented as ready for operating, and is mounted upon sliding rails which are attached to the wooden *bedplate*. Two adjusting screws, one on each side of the

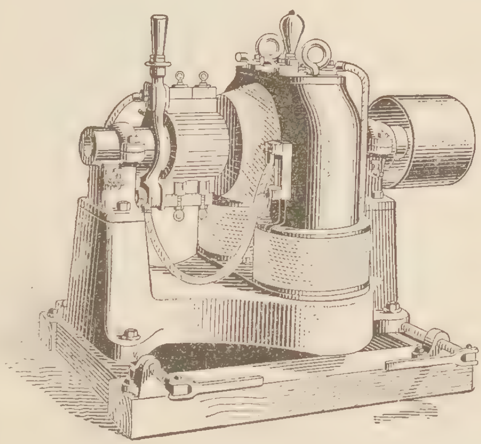


FIG. 52.

machine, are used to move the dynamo along the rails, thereby loosening or tightening the belt as the circumstances may require. The current passes from the brush holders through flexible copper cables to two terminals fastened to, but insulated from, the pole pieces; from the terminals the current passes through the series winding on the field or magnetizing coils, and thence to a small connection board on the top of the pole pieces. An incandescent lamp is connected between the main terminals of the connection board, and is used to indicate when the machine is generating its normal E. M. F. A lamp used for this purpose is usually called a **pilot lamp.**

58. A multipolar dynamo for developing a constant potential and ready for operating is shown in Fig. 53. In

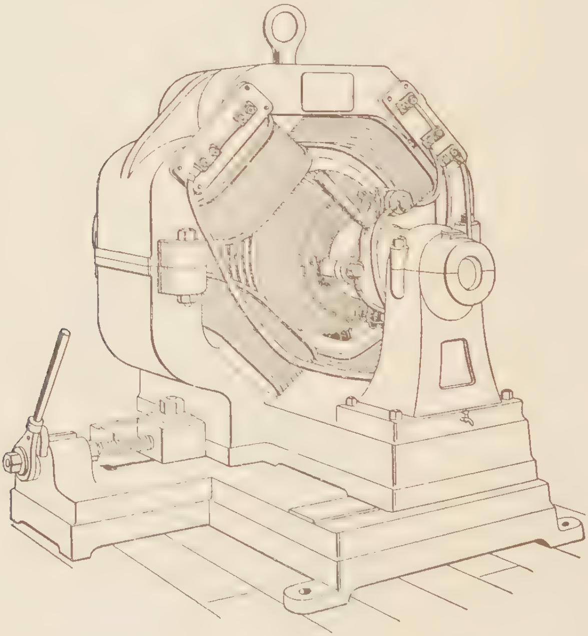


FIG. 53.

this machine the frame is made of two main castings; one consisting of the upper magnetic yoke and two pole pieces,

and the other consisting of the lower magnetic yoke and two pole pieces, from which project two extensions for supporting the pillow-blocks. The dynamo slides upon a cast-iron bedplate, and adjustment is made by a screw, as in the case of the bipolar dynamo.

The two dynamos previously described are illustrations taken from actual practice and embody some special features which are not found in other machines of the same character; they were selected, however, on account of their simplicity, to convey to the student a general idea of how electrical principles are combined with mechanical construction.

EFFICIENCY OF CONSTANT-POTENTIAL DYNAMOS.

59. As previously stated, a dynamo is a machine for converting or transforming mechanical into electrical energy. In any transformation of energy, the total amount of energy is constant; when energy which is manifested in one form disappears, the same quantity will always appear again in another form or in several other different forms. This action is exactly that which takes place in a dynamo. A certain amount of mechanical energy is delivered to the armature shaft of the dynamo by a belt or some other transmitting device; a large portion of the energy is converted into electrical energy in the armature conductors and is transmitted to the external circuit, while the rest of the energy, usually the smaller portion, is converted directly or indirectly into heat energy in the different parts of the dynamo itself. The amount of energy delivered to the armature shaft is always equal to the energy appearing in the external circuit from the brushes, plus the energy converted into heat in the dynamo itself.

In a dynamo the mechanical energy delivered to the armature shaft is usually called the **input**; the electrical energy appearing in the external circuit from the brushes is called the **output**; and the energy converted into heat directly or

indirectly in the dynamo itself is termed **energy losses**, or simply **losses**. This last term is not a strictly true one; for the energy converted into heat in the dynamo is lost only in relation to its utility—it cannot be utilized to an advantage, and if too intense, endangers the life of the machine.

From what has been stated, it will be seen that the *input* of a dynamo is always equal to the *output* at the brushes, plus the *losses* in the machine itself; or, in other words, the losses in the dynamo are equal to the difference between the *input* and the *output*. It is assumed in the above statement that the *input*, *output*, and *losses* are reduced to the same units. For example, suppose that 20 horsepower is delivered to the armature shaft of a dynamo where the *output* from the brushes to the external circuit is 13,428 watts. Reducing the 20 horsepower to watts gives $20 \times 746 = 14{,}920$ watts; hence, the losses in the dynamo are equal to the difference between the input of 14,920 watts and the output of 13,428 watts, or $14{,}920 - 13{,}428 = 1{,}492$ watts.

60. It is more convenient, however, to express the relation of the *input*, *output*, and *losses* of a dynamo in percentage; that is, the output as well as the losses may be expressed as a certain per cent. of the input. The relation of the input to the output of a dynamo, expressed in percentage, is termed the **efficiency** of the machine.

Let I = the input of a dynamo;
O = the output;
E = the per cent. efficiency.

Then, the per cent. efficiency of a dynamo may be found by the formula

$$\mathsf{E} = \frac{100 \times O}{I}. \qquad (2.)$$

That is, *to find the per cent. efficiency of a dynamo, divide the output in watts by the input in watts and multiply by 100.*

For instance, in the above example, the efficiency, by formula **2**,

$$\mathsf{E} = \frac{100 \times 13{,}428}{14{,}920} = 90 \text{ per cent.}$$

61. The relation of the input to the heat losses in a dynamo, expressed in percentage, is termed the **per cent. loss.**

Let L = per cent. loss. Then, the per cent. loss in a dynamo may be found by the formula

$$L = \frac{100(I - O)}{I}. \qquad \textbf{(3.)}$$

That is, *to find the total per cent. loss in a dynamo, divide the difference between the input and the output in watts by the input in watts and multiply by 100.*

EXAMPLE.—(*a*) What is the per cent. efficiency of a dynamo if 10 horsepower is delivered to the armature shaft and the output from the brushes is equivalent to 6,341 watts? (*b*) What is the total per cent. loss in the dynamo when running under these conditions?

SOLUTION.—Reducing the input of 10 H. P. gives $10 \times 746 = 7{,}460$ watts input. (*a*) By formula **2**, the efficiency

$$E = \frac{100 \times 6{,}341}{7{,}460} = 85 \text{ per cent. Ans.}$$

(*b*) By formula **3**, the total loss

$$L = \frac{100\ (7{,}460 - 6{,}341)}{7{,}460} = 15 \text{ per cent. Ans.}$$

The efficiency of a dynamo depends upon its character, construction, condition when tested, its capacity (or output), losses, and various other conditions; in fact, two dynamos of the same construction and capacity seldom show exactly the same efficiency. The following list, however, will give the student a general idea of the approximate per cent. efficiencies which should be obtained from constant-potential machines of different capacities, or outputs, under ordinary conditions met with in practice:

From 750 to 1,500 watts output inclusive, about 75% efficiency.

From 3,000 to 5,000 watts output inclusive, about 80% efficiency.

From 7,500 to 10,000 watts output inclusive, about 85% efficiency.

From 15,000 to 100,000 watts output inclusive, about 90% efficiency.

From 150,000 watts output and upwards, from 91 to 93% efficiency.

The method of actually testing a dynamo to find its efficiency and losses is beyond the scope of this section; the above, however, will serve as a guide to the student when computing the necessary power required to drive dynamos of different capacities or outputs.

62. When the output of a dynamo and its corresponding efficiency are given, the input necessary may be found by the formula

$$I = \frac{100 \times O}{E}. \qquad (4.)$$

That is, *the input necessary to drive a dynamo, when its output and efficiency at that output are given, is obtained by dividing the output by the per cent. efficiency and multiplying the quotient by 100.*

EXAMPLE 1.—The efficiency of a constant-potential dynamo is found to be 85% when giving an output of 6,341 watts; find the input in horsepower necessary to drive its armature shaft under these conditions.

SOLUTION.—By formula **4**, the input necessary $I = \frac{100 \times 6{,}341}{85}$ $= 7{,}460$ watts. The equivalent of 7,460 watts in horsepower is $\frac{7{,}460}{746}$ $= 10$ horsepower, which is the power required to drive the armature shaft of the dynamo under the stated conditions. Ans.

When the input of a dynamo and its corresponding efficiency are given, the output may be found by the formula

$$O = \frac{I\,E}{100}. \qquad (5.)$$

That is, *the output of a dynamo, of which the input and the efficiency at that input are given, is obtained by multiplying the input by the per cent. efficiency and dividing by 100.*

EXAMPLE 2.—An input of 35 horsepower is delivered to the shaft of a dynamo; if its efficiency at that input is 89.5%, find its output in watts.

SOLUTION.—The equivalent of 35 horsepower is $35 \times 746 = 26,110$ watts. By formula **5**, the output of the dynamo under these conditions,

$$O = \frac{26,110 \times 89.5}{100} = 23,368.45 \text{ watts. Ans.}$$

63. The total loss of power in a dynamo can be separated into smaller losses, depending upon the manner in which the loss is produced and the part of the dynamo in which it occurs. In ordinary cases, all the losses will come under one or more of the following heads:

1. Mechanical-friction loss.
2. Core loss.
3. Field loss.
4. Armature loss.

64. Friction Losses.—The larger part of the loss due to mechanical friction takes place between the bearings and journals. The brushes rubbing on the commutator produce some friction and consequent loss, but the amount is small, unless carbon brushes, under heavy pressure, are used. The per cent. of power lost in mechanical friction necessarily depends upon the construction and condition of the bearings and journals, upon the size of the machine, and, to some extent, on the method of driving the armature shaft. Under ordinary conditions, the loss in mechanical friction should not exceed 5% of the input of dynamos from 1,500 up to about 10,000 watts output, and 3% of the input of dynamos from 15,000 to 100,000 watts output For example, suppose that a dynamo has an efficiency of 88% at its rated output of 22,000 watts, and a test shows that 2.5% of the input is lost in mechanical friction. The total loss in the machine is $100 - 88 = 12\%$, of which 2.5% is lost in friction; the remaining 9.5% loss is due to other causes. The total input to the machine, from formula **4**, is $\frac{22000}{88} \times 100 = 25,000$ watts; hence, the power lost in friction is $\frac{25,000 \times 2.5}{100} = 625$ watts.

65. Core Losses.—The **core loss** is the energy converted into heat in the iron disks of the armature core when

they are rotated in the magnetic field. A small portion of this loss is due to eddy currents generated in the revolving core disks, as explained in Art. **16**; the larger portion of the loss is due to a *magnetic friction* which occurs whenever the direction of the lines of force is rapidly changed in a magnetic substance. When the magnetism of an electromagnet is rapidly reversed—that is, when the direction of the lines of force is suddenly changed several times in rapid succession by reversing the direction of the magnetizing current—the iron or steel in the core becomes heated, which necessitates a certain amount of energy being expended. This effect is due to a kind of internal *magnetic friction* by reason of which the rapid changes of magnetism cause the iron to grow hot. This effect is called **hysteresis.**

The energy expended by hysteresis is furnished by the force which causes the change in the magnetism, and in the case of an electromagnet where the magnetism is reversed by the magnetizing current being reversed, the energy is supplied by the magnetizing current.

The same effect is produced when the iron of the armature core is rapidly rotated in the constant magnetic field of the dynamo; this case differs from the electromagnet only in the fact that the magnetic lines of force remain at rest and the iron core is made to rotate. Since the core is rotated from the armature shaft, the energy lost in hysteresis is furnished by the force which drives the shaft.

The loss of energy due to hysteresis depends (1) upon the hardness and quality of the magnetic substance in which the magnetic change takes place, (2) upon the amount of metal in which the reversal takes place, (3) upon the number of complete reversals of magnetism per second, and (4) upon the maximum density of the lines of force in the metal. Building the core of iron disks does not affect the hysteretic loss; it only reduces the eddy currents. Hysteretic loss is greatly reduced by using soft annealed iron, which exhibits only slight traces of residual magnetism; for where the residual magnetism is large, the loss due to hysteresis is large in proportion. The hysteretic loss

increases in a certain ratio with the magnetic density and the number of reversals per second; hence, these quantities are kept within reasonable limits. In well-designed dynamos the magnetic density in the armature rarely exceeds 85,000 lines of force per square inch, and the maximum number of complete reversals of magnetism in the armature core is about 133 per second. In bipolar dynamos the number of complete reversals of magnetism in the armature is equal to the number of revolutions per second at which the armature shaft is driven; in multipolar machines the number of reversals is equal to the number of revolutions of the armature shaft multiplied by the number of *pairs of poles*. For example, if the armature of a four-pole dynamo is driven at 600 revolutions per minute, or 10 revolutions per second, the number of complete reversals of magnetism in the armature core is $10 \times 2 = 20$ per second.

In a well-designed dynamo, the core loss, including eddy currents and hysteresis, should not exceed 2% of its input when delivering its rated output from the brushes.

66. Field Losses.—In self-exciting dynamos, a portion of the electrical energy generated in the armature is required to excite the field magnets. This energy is considered as one of the losses of the dynamo, since it does not appear in the external circuit and it is entirely dissipated in the form of heat.

In a series-connected dynamo, where the total current from the armature passes through the magnetizing coils, the power in watts is equal to the square of the current, multiplied by the resistance of the series turns. If, then, C is the total current from the armature, r is the total resistance of the series coils, and W is the watts lost in the series coils, then, $W = C^2 r$. For example, suppose that a series dynamo generates 200 volts between its terminals when a current of 100 amperes is flowing from its brushes through its series coils and through the external circuit. The total output of the dynamo is, then, $100 \times 200 = 20{,}000$ watts. If the total resistance of the series coils is .1 ohm, then the number

of watts (W) required to excite the field magnets $= C^2 r$ $= 100^2 \times .1 = 100 \times 100 \times .1 = 1{,}000$ watts.

67. In a shunt dynamo which generates a nearly constant potential for limited strengths of current in the armature, the field coils usually consist of a large number of turns of fine wire, offering a high resistance compared with the field coils of a series dynamo. The two terminals or ends of the shunt field coils are connected to the positive and negative brushes, respectively, of the dynamo in parallel with the external circuit, thereby allowing the full potential of the dynamo to act against the resistance of the coils. Then, from Ohm's law, the current in the shunt coil is equal to the electromotive force of the brushes divided by the resistance of the coils. Let E_e represent the difference of potential between the brushes of the dynamo when running at normal speed and fully excited, let r_s represent the resistance of the shunt coils, and C_s represent the current in the shunt coils. Then, from Ohm's law, the current in the shunt coils is given by the formula $C_s = \frac{E_e}{r_s}$. For example, suppose that a shunt dynamo, when running at a constant speed, generates a constant difference of potential of 110 volts, and the resistance of the magnetizing coils from the positive connection to the negative connection is 55 ohms; or $E_e = 110$ volts and $r_s = 55$ ohms. Then, the current in the shunt coils would be given by substituting these values in the above formula, or $C_s = \frac{E_e}{r_s} = \frac{110}{55} = 2$ amperes.

This gives the strength of current in the shunt coils, but does not indicate the amount of power required to constantly excite the field magnets. The power in watts is $W = C E$; that is, it is equal to the current in amperes flowing through the shunt coils multiplied by the difference of potential in volts between the terminals of the shunt coils. We have found in this case that the current $C = 2$ amperes and the E. M. F. $E = 110$ volts; then, $W = 2 \times 110 = 220$ watts, which represents the power required to excite the field magnets.

All other conditions being similar, the same number of watts will be dissipated in a shunt field coil as in a series coil, provided an equal amount of magnetizing force is produced in the two cases.

68. In a compound-wound dynamo, the field loss consists of two losses, one in the series coil and the other in the shunt coil. The loss in the series coil depends upon the strength of current flowing from the dynamo, as in the case of a simple series dynamo, while the loss in the shunt coil is constant, irrespective of the load on the machine; provided, of course, the dynamo generates a constant electromotive force for all loads. This can readily be understood from the following example: A dynamo is compounded to generate 220 volts between its terminals for all loads up to its rated capacity; that is, when the current from the armature becomes stronger and the difference of potential between the terminals tends to fall, the current in passing through the series coil strengthens the field magnets sufficiently to keep a difference of exactly 220 volts between the terminals of the dynamo. Assume the resistance of the shunt coil to be 275 ohms and that of the series coil to be .055 ohm. At a rated output of 4,400 watts, the current flowing through the series coil and into the external circuit is $\frac{4400}{220} = 20$ amperes (assuming the connections are made for a *short shunt*). At all loads the current in the shunt coil is $C_s = \frac{E_e}{r_s} = \frac{220}{275}$ $= .8$ ampere, and the loss of power in the shunt coil is $W_s = E_e \times C_s = 220 \times .8 = 176$ watts; even when the external circuit is open the loss in the shunt coil remains constant, or 176 watts in this particular case. The loss in the series coil, however, varies directly with the square of the current passing through it. In this example, the loss in the series coil is $W = C^2 \times r = 20^2 \times .055 = 22$ watts; at half load, or 10 amperes, the loss is $W = 10^2 \times .055 = 5.5$ watts, etc.; at no load there is no current in the series coil, and, consequently, no loss. The total field loss in a compound dynamo is the sum of the losses in the series and shunt coils. For

instance, in this example, the total field loss at full load is 198 watts; at half load, 181.5 watts, and at no load, 176 watts.

69. The amount of power lost or dissipated in the field coils of a dynamo depends (1) upon the capacity of the dynamo, (2) upon its design, and (3) upon the amount of copper used in the coils. In the last condition it is obvious that in order to produce a certain number of *ampere-turns*, the current in amperes required could be made exceedingly small by using a large number of turns of copper wire, thereby reducing the electrical loss. A limit is reached, however, where it is not economical from a commercial standpoint to increase the amount of copper in order to save in electrical loss.

The per cent. loss in the field coils of dynamos varies from about 10% of the input to dynamos having an output of about 1,000 watts to as low as 1.5% to 2% of the input to dynamos having an output of 100,000 watts and upwards. For example, suppose that the input to a dynamo from an engine was 100 horsepower and the loss in the field coils was 2.5%. Under these conditions, how many watts are lost or dissipated in the field coils? Changing the input from horsepower to watts gives $100 \times 746 = 74,600$ watts, since 1 horsepower is equivalent to 746 watts. Hence, the number of watts lost in the field coils is $74,600 \times .025 = 1,865$ watts.

70. Armature Losses.—The principal armature loss is that produced by the current in flowing against the internal resistance of the armature, that is, the resistance of the armature *conductors*. The *core losses* previously described could also be classed as part of the armature losses, but it is usual to consider them apart. The armature loss proper is usually termed the **copper,** or **wire, loss,** since it is due to the resistance of the armature conductors, which are composed of copper wire or bars. The internal resistance of an armature is an exceedingly variable quantity, depending upon the form, construction, size, number of conductors, size of conductors, etc. In constant-potential dynamos,

generally speaking, the internal resistance of the armature must necessarily be comparatively small, since it determines the maximum strength of current that can be obtained from the dynamo, as will be seen subsequently.

The armature loss depends upon the amount of internal resistance and upon the strength of current flowing through the armature conductors. In a given armature the internal resistance remains constant at equal temperatures, while the strength of current varies with the load upon the dynamo at that particular moment; in other words, this loss only occurs when there is a current flowing through the armature—the stronger the current, the greater is the loss, and vice versa. As previously shown, in all cases where an electric current flows against the resistance of a conductor, the loss of power in watts is equal to the resistance of the conductor in ohms multiplied by the square of the current in amperes; hence, in an armature the number of watts lost in the armature conductors is equal to the square of the current in amperes flowing through the armature multiplied by the internal resistance in ohms of the armature from the positive to the negative brush. If C represents the total current in amperes flowing through the armature and r_i the internal resistance in ohms from the positive to the negative brush, then $W_i = C^2 r_i$, where W_i is the number of watts lost in the armature conductors. From this fact, this armature loss is also designated as the **C^2 r loss.** For example, suppose that the internal resistance of an armature from brush to brush is .125 ohm, and a total current of 40 amperes is flowing through the armature. Determine the number of watts lost in the armature. Let $C = 40$ amperes and $r_i = .125$ ohm; then, $W_i = C^2 r_i = 40^2 \times .125 = 200$ watts.

The per cent. loss in armatures of constant-potential dynamos varies from about 12% of the input to dynamos having a rated capacity of about 1,000 watts to as low as 1.5% to 2% of the input to dynamos having a rated capacity of about 100,000 watts and upwards. For example, suppose that a dynamo was working under a load which required 50 horsepower to run it, and, at this rating, the armature

loss alone amounted to 3% of the input; determine the number of watts dissipated or lost in the armature conductors. Changing the input from horsepower to watts gives $50 \times 746 = 37,300$ watts, since 746 watts are equal to 1 horsepower. The armature $C^2 r$ loss is therefore 3% of the input, or $37,300 \times .03 = 1,119$ watts.

71. Other Losses.—Aside from the four principal losses mentioned, other small losses occur in some machines when the armature is revolving. If large conductors are used in the winding of the armatures, a difference of potential is sometimes generated between the edges of the conductor in such a manner as to give rise to small eddy or local currents in the conductors themselves, and which do not appear in the external circuit and are useless. In some cases these local currents dissipate considerable energy and heat the armature badly when the machine is not loaded; but in a well-designed dynamo they are too small to be considered.

In an armature in which the conductors are wound in slots cut in the core disks, the teeth between the slots have a tendency to disturb the position of the lines of force where they enter and leave the polar faces. This movement causes local or eddy currents to be generated in the pole pieces, thereby dissipating a certain amount of energy. These eddy currents in the pole pieces are sometimes termed **Foucault currents**, in memory of the man who first recognized their existence. In order to prevent these Foucault currents, the pole pieces of machines having toothed armatures are frequently laminated. Other local currents may occur in various parts of some dynamos on account of bad design, but it is only necessary here to treat specifically upon such losses as are common to all dynamos and impossible to eliminate.

72. From the four previous articles, the following summary will be a help to establish the rules of efficiency and losses:

Input = the power driving the dynamo, which is derived from some outside agency.

Output = input minus the total losses.

Total losses = the sum of the friction, core, field, armature, and other losses.

Per cent. efficiency $= \frac{\text{input minus total losses}}{\text{input}} \times 100$, or $\frac{\text{output}}{\text{input}} \times 100$.

Per cent. loss in friction $= \frac{\text{friction losses}}{\text{input}} \times 100$.

Per cent. loss in core $= \frac{\text{core losses}}{\text{input}} \times 100$.

Per cent. loss in field $= \frac{\text{field losses}}{\text{input}} \times 100$.

Per cent. loss in armature $= \frac{\text{armature losses}}{\text{input}} \times 100$.

THE OUTPUT OF CONSTANT-POTENTIAL DYNAMOS.

73. If a dynamo is so constructed as to give a constant potential at any load, it is evident that the current flowing is inversely proportional to the resistance of the external circuit; that is, if the external resistance is reduced, the amount of current will be correspondingly increased. There is a limit, however, to the amount of current that any given machine can give out, depending on one (or both) of two factors; namely, the **heating** and the **sparking.**

The heat that is being continually generated in the armature and field coils of a dynamo when working under load, due both to the $C^2 r$ *loss* and the *core loss*, is given off from the surface of the armature and of the whole machine to the surrounding air. This giving off of heat can only occur when the dynamo is hotter than the air, for if two bodies

are equally hot, one cannot give any heat to the other. Conversely, the greater the difference in temperature between two bodies, such as a dynamo armature and the surrounding air, the more heat will be given from the hot body to the cool.

74. When a dynamo is first started, it is at about the same temperature as the air, so that when the conductors in the armature begin to generate heat, this heat cannot pass off to the air, but instead it raises the temperature of the armature, until it is enough hotter than the surrounding air to cause all the heat which is being generated to be given off.

If the amount of heat generated is practically constant, as will be the case if the load remains constant, the temperature of the armature will also remain constant, because the heat is given off as fast as generated; and if the load is increased so as to increase the amount of heat generated, the temperature will again rise until the armature is enough hotter than the air to give off all this increased amount of heat.

It is evident, then, that when other conditions remain the same, the greater the load on a dynamo armature, that is, the more current it gives, the hotter it will get.

Now, at a certain temperature, the materials used in insulating the conductors of the armature, such as cotton, silk, shellac, paper, etc., will become *carbonized*, that is, charred, or otherwise rendered useless as insulating material. For a short time these materials will withstand a temperature considerably above the boiling point of water (212° F.), but it has been found that if they are *continually* subjected to a temperature greater than about 180° F., they will gradually become carbonized; hence, as armatures are expected to last several years, they should never be subjected to a continual temperature greater than about 170° F. Consequently, the amount of current which will cause a dynamo armature to heat to about 170° F. is the limiting amount which that armature can *safely* give.

75. As an armature must be a certain number of degrees hotter than the air in order to give off the heat generated, it is evident that if the air itself were originally of a high temperature, the armature would actually have a higher *temperature* when giving off a certain amount of heat than if the air were cooler; that is, for a certain amount of heat generated, the temperature of the armature will rise to a certain number of degrees *above the temperature of the air*. The average temperature of the air in places where dynamos are installed is often as high as 90° F., so the allowable rise in temperature of the armature above that of the air is about $170 - 90 = 80°$ F., and dynamos are usually rated according to this rise in temperature.

As *still* air is a very poor conductor of heat, most of the heat given off to it is carried away by the motion of the air; this motion is partly due to the air-currents set up by the rise of the heated air and the flowing in of the cooler air to take its place, but mainly to the air-currents set up by the motion of the armature itself. This latter effect is usually greater in ring than drum armatures, due to the more open construction of the former and to the *fan* action of the spider arms.

The heat generated in the field coils is disposed of in the same way as that of the armature; that is, it is given off to the surrounding air. The rise in temperature of the field coils is subject to the same limitations as the rise of the armature; i. e., it is usually limited to about 80° F. above the temperature of the air.

76. By the *sparking* of a dynamo is meant the sparks which appear at the brushes, due to the *reversal of the current in the armature coils*. If the commutator is out of true or has one segment higher or lower than the others, or from other similar causes, there will be flashes or sparks at the brushes; but these are merely *mechanical* faults which can be easily remedied, and this is not what is meant by *sparking*. Referring to Fig. 28, it will be seen that in the armature coil $a' p p'$, when in the position shown, the general direction of the current is from right to left; but as soon as

it moves into the position occupied by coil $b' a a'$, the general direction of the current is from left to right. Between these two positions the direction of the current must have been reversed, and this occurs during the time that the brush $+B$ is resting on *both* the commutator segments which are connected to this coil ($a' p p'$).

Now, it has been shown that if the amount of current in a coil is suddenly increased or decreased, the *self-induction* of the coil tends to set up an E. M. F. in the coil which *opposes* the change in the strength of the current. Hence, when the current is reversed in the armature coil as it passes from one side of the brush to the other, the self-induction of the coil tends to prevent this reversal, so that when one of the commutator bars to which the coil is connected passes out from under the brush, the current flowing from the side of the armature into which the coil is entering (the left side in Fig. 28) in trying to pass through this coil is opposed by the E. M. F. of self-induction of the coil. Instead of passing through the coil, then, the current jumps from the commutator bar through the air to the end of the brush, making a spark. The same action takes place at each point of commutation.

In order to prevent this sparking, which burns the commutator bars and the brushes, the brushes are shifted forwards ahead of the actual neutral point, until at the same instant that the current in a coil is reversed the coil is moving in the edge of the magnetic field that spreads out from the pole pieces, which generates in the coil an E. M. F. that is *opposite in direction to the E. M. F. of self-induction.* The consequence of this is that the E. M. F. of self-induction is diminished, which decreases the sparking. If the brushes are shifted to just the right position, the E. M. F. generated in the coil by the magnetic field will just equal the E. M. F. of self-induction, and there will be no opposition to the reversal of the current, hence no sparking. This is seldom actually done, as the E. M. F. of self-induction changes with every change in the strength of the current; but the effect of a certain amount of shifting of the brushes will usually

so nearly counterbalance the E. M. F. of self-induction that the sparking will be slight at different loads.

77. It has been shown that the current in the armature winding reacts upon the magnetic field, forcing the actual neutral point ahead (in the direction of rotation). Now, if the brushes are moved ahead of this neutral point to avoid sparking, the effect is to move the consequent poles (due to the current circulating in the armature winding) also ahead, which shifts the neutral point still farther ahead, which requires a further slight shifting of the brushes. As long as the field due to the magnetizing coils is much stronger than the reactive effect of the armature, this action is slight, so that only a slight shifting of the brushes is necessary for practically sparkless operation. As the current in the armature increases, its reactive effect grows stronger, and a movement of the brushes is followed by a considerable movement of the neutral plane. Indeed, if the current in the armature is strong enough, the brushes may be shifted more than half way around the commutator without coming to the sparkless position. There is, therefore, a limit to the amount of current which can be taken from an armature (aside from its heating limit), which is reached when any further amount of shifting of the brushes will not afford sparkless commutation.

This amount of shifting is generally confined to the space between the tips of the pole pieces; that is, the brushes may be shifted until the coil short-circuited by a brush is at or just under the tip of a pole piece.

In dynamos of good design, the heating limit and sparking limit are reached with about the same current; that is, a current which will raise the temperature of the armature above that of the air by the amount decided upon as a limit will also necessitate the brushes being shifted to the maximum allowable extent. In some modern railway generators, the output is limited more by the heating than by the sparking. Such machines may stand a 50 per cent. overload without excessive sparking. Moreover, by careful designing

and the use of carbon brushes, sparkless commutation can be obtained without shifting the brushes forwards as the load comes on. In fact, where the load fluctuates rapidly, it would be practically impossible to shift the brushes and for such work a fixed point of commutation is almost essential.

78. It is evident that while a brush is resting on two commutator bars at the same time, the coil connected between these two bars is *short-circuited*, the current from the two sides of the armature passing into the brush, one-half through each of the two commutator bars, without passing through the short-circuited coil. The resistance which the current meets in passing from the bars into the brush is evidently the *contact resistance* of the surfaces which are in contact. When the brush rests equally on both commutator bars, the contact resistance opposed to each half of the current is the same; but as one of the bars moves out from under the brush and the other moves farther under it, the contact resistance is altered, and there is more opposition to the passage of one-half the current into the brush than there is to the other. Now, with *metallic* brushes, which have a very low contact resistance if properly made, this difference is not enough to give any appreciable opposition to the current until the commutator bar is actually leaving the brush; hence, the current is *suddenly* forced to pass through the coil which has just been short-circuited. With *carbon* brushes the contact resistance is much greater than with metallic brushes; when the two bars are equally under the brush, this contact resistance is opposed equally to the current from each half of the armature, but as the one commutator bar begins to move from this position, the resistance opposing the current which is passing from that bar into the brush is great enough to force a part of the current around through the short-circuited coil and into the brush through the *other* commutator bar, in spite of the E. M. F. of self-induction of the coil.

From this it follows that, with metallic brushes, much more care must be taken than with carbon brushes, to place the

short-circuited coil in a field which will generate an E. M. F. equal to the E. M. F. of self-induction, since the absence of sparking depends mainly on this point. With carbon brushes the absence of sparking depends both on generating an E. M. F. in the coil and on the contact resistance of the brush. On account of the increased resistance of contact, carbon brushes require less shifting for variations in load than do metallic brushes, and are generally used on machines where the variations in load are so frequent and extensive that a great deal of time would be spent in shifting the brushes, if this had to be done for every change in the load.

79. If the brushes are shifted so far forwards that the E. M. F. generated in the short-circuited coil is *greater* than the E. M. F. of self-induction, not only will the latter be neutralized, but a current will be sent around the coil through the commutator bars and the brush which short-circuits the coil. If this current is greater than the current which one-half of the armature is supplying to the external circuit, it is evident that when the short-circuited coil moves over and becomes a part of that half of the armature, its current will be *reduced;* this reduction is opposed by the self-induction of the coil, as before, and sparking results. Since the circuit of the short-circuited coil is partly through the brush and its contact with the commutator bars, it is evident that with metallic brushes of low resistance the liability of the current in this coil becoming excessive is greater than with carbon brushes of (comparatively) high resistance. For the reason, therefore, that they are of higher resistance, carbon brushes will spark less than metallic brushes under the same conditions.

DIRECT-CURRENT MOTORS.

80. It has already been explained that a conductor carrying current at right angles to a magnetic field will move across the field. This is, in brief, the principle on which an electric motor operates. If we take an ordinary direct-current dynamo and, instead of driving it from some outside

source of power and making it generate an E. M. F., we supply it with current from some outside source, say another dynamo, the machine will run as a motor and deliver power at its pulley. A direct-current motor, then, is the same as a dynamo, so far as its construction goes. The difference between a dynamo and a motor has more to do with the way in which the machines are used than with any radical difference in their construction. At one time it was thought that motors should be constructed different from dynamos, but it is now known that the machine that makes a good dynamo will nearly always make a good motor. Of course, motors often differ considerably from dynamos in their mechanical details, because motors must often be adapted to special work for which the ordinary mechanical construction of a dynamo would be unsuitable. For example, railway motors must stand all sorts of abuse, and hence must be enclosed as much as possible. As regards their electrical features, however, direct-current dynamos and motors are the same; when a machine is used as a dynamo, it is supplied with power and it converts this power into electrical energy; when it is used as a motor, it is supplied with power in the shape of an electric current, the reaction between the current in the armature conductors and the magnetic field set up by the field magnets forces the armature to revolve, and the machine, therefore, converts the electrical energy supplied at the brushes into mechanical energy delivered at the pulley.

CLASSES OF MOTORS.

81. Motors, like dynamos, may be divided into several classes according to the method used for exciting their field magnets. We may then class them as *series-wound*, *shunt-wound*, *compound-wound*. The last class may be subdivided into *differentially wound* and *accumulatively wound*, according as the series field coils are connected so as to *oppose* or *aid* the shunt coils. Nearly all motors in common use are operated

at constant potential, and we will confine our remarks here to motors that are so operated.

82. Shunt-Wound Motors.—Shunt-wound motors are very extensively used for stationary work for operating all classes of machinery where a fairly constant speed is required. A constant-potential shunt-wound motor is the same as regards construction as the corresponding shunt-wound dynamo. When supplied with a constant pressure, it will run at nearly constant speed, no matter what may be the load, up to the limit of the machine. The speed drops off slightly with an increase of load, but the falling off is slight if the motor is well designed. A shunt-wound motor will give a good starting effort if the field is fully excited before the current is allowed to pass through the armature. For stationary work, the shunt-wound motor is the one most largely used.

83. Series-Wound Motors.—These motors are used most largely for work when a wide variation in speed is desired, where the motor is to be started and stopped frequently, and where a strong starting effort is needed. For these reasons they are used on street railways and for traction work generally, for hoists, electric cranes, and in some cases for pumps and similar machinery. Thousands of series-wound, direct-current motors are in use for operating street cars alone. Since the field is in series with the armature, the strength of the field depends on the current flowing through the motor. If at starting a large current is allowed to flow, the field is made very strong, and as the current in the armature is also very large, a powerful starting effort is the result. This is a valuable feature if the motor is to be used for traction or hoisting work. The speed of a constant-potential series motor varies widely if the load on it is varied, because every change in load produces a corresponding change in the field strength. If the load is thrown off entirely, the motor will race, and may reach a speed high enough to injure itself.

84. Compound-Wound Motors.—These motors are not largely used, compared with the other two classes. They are used mostly for special purposes, such as operating printing presses, looms, etc. When a speed that is very nearly constant under all loads is required, the differentially wound motor is used. When a motor is required that will have a fairly good starting effort combined with the property of approximately constant speed, the accumulatively wound motor is employed. In this motor the series coils aid the shunt coils, and when starting, the heavy current through the series coils strengthens the field, and thus gives a strong starting effort, or *torque*, as it is called.

OPERATION OF DYNAMOS AND MOTORS.

INSTALLATION.

1. Location.—The location of a large dynamo or motor is a matter generally determined by local surroundings; that is, the position of the dynamo depends on where its engine may be, and the disposition of the motor depends on what it is to drive and where it is located. Assuming, however, that the conditions are such that the selection of a site for the dynamo or motor is not hampered by other considerations than that the machine shall be put in a place best adapted to itself, the following points should be kept in mind: It should be kept in a clean, dry, cool place, out of reach of drippings from steam and water pipes, and protected from dropping of water due to the condensation that sometimes takes place on an iron roof. The machine should preferably be placed where there can be a draft of air across it from windows or doors on opposite sides, and in such cases, if it is located on the ground floor, there should be ample means for sprinkling the street in the vicinity to keep down the clouds of dust that are otherwise sure to be present in dry weather. This precaution will permit a free circulation of air when it is most needed—in the hot summer months.

The space surrounding the machine should be clean and free from all obstructions. Where the machine is controlled

from a switchboard, a man should be able to go from one to the other without going through a belt or past a number of obstructions. Dust from the street is injurious to the commutator, bearings, and general insulation of electrical machines, but dust from a coal pile or any kind of grinding or turning machine is even more so; therefore, the engine and dynamo rooms should be protected from the dust incidental to coal handling, and no emery wheels, grinders, speed lathes, etc. should be allowed in the room. Where motors are installed in rolling mills, forge rooms, carbon works, or places where a great deal of power grinding or finishing is done, the motor should be of an enclosed type, its bearings should be protected, just as those of a grinder are, and the machine should be properly caged.

2. Foundations.—Every machine of 25 horsepower, or more, should be provided with a substantial foundation, and this foundation should, if possible, be independent of the floor and walls of the building in which it is installed, to avoid communicating to them the very disagreeable vibration incidental to the running of the machinery. Where there are several machines to be installed, the idea is best carried out by having the whole floor space subconcreted and capped with a layer of cement or a wood floor. Where a single machine is to be installed, it is sufficient to limit the foundation to a little more than its floor area. In any case, solid brickwork is the best foundation, but where its use is impracticable, a substantial wooden frame construction can be used. Even where the concrete or brick foundation is used, it is customary to cap this with a hardwood frame, served with a high-grade insulating compound of some sort; the layer of wood serves not only to insulate the metal frame of the machine from the ground, but it acts as a cushion to take up the blows and vibration. The insulation feature must not be defeated by having the bolts that secure the wood frame to the masonry come in contact with those that secure the metal frame of the machine to the wood.

No rule in regard to the depth of the foundation can be given to cover all cases, as the subsoil is so different in different places. In one section, bed rock will be found a few feet from the surface, while in another section of the country it will be necessary to drive piles to support the foundations for the heavier machines. Fig. 1 shows a style of foundation very much used; the foundation proper is made of brick laid with 1 part of the best cement to 2 parts of good, sharp sand. The surplus of excavation is filled in with a mixture of broken stone and cement, which is capped to a surface with pure cement. The masonry is built around the anchor bolts.

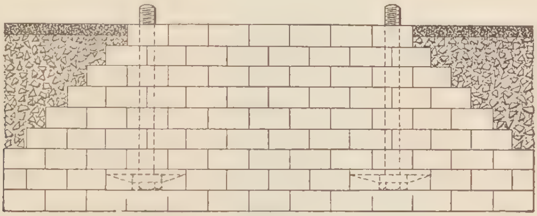


FIG. 1.

Wherever the machine is to be belt-driven, means should be provided for tightening or slacking the belt. On most machines this is usually accomplished by screws or by mounting the machine on rails or on a subbase and moving the machine by means of a ratchet lever and screw. As an example of this we may take the machine shown in Fig. 2. The foundation should in every case be so disposed that the distance between the driving and driven centers will allow one side of the belt to run looser than the other. This distance should be at least four times the diameter of the larger pulley.

3. Erection.—Small machines are, as a rule, shipped complete and ready to run, so that there is nothing to do but to put them in place, put the pulley on, and line them up. Large machines cannot be shipped with safety in an assembled condition, and some are so large that they could

not be gotten through the door of a closed car; so they are dismounted and the parts marked and packed in separate parcels. It then falls upon the roadman or the purchaser to assemble them at their destination. This work should not be undertaken by one not familiar with such work, and even an expert should not be above consulting the blueprints and the marks on the parts.

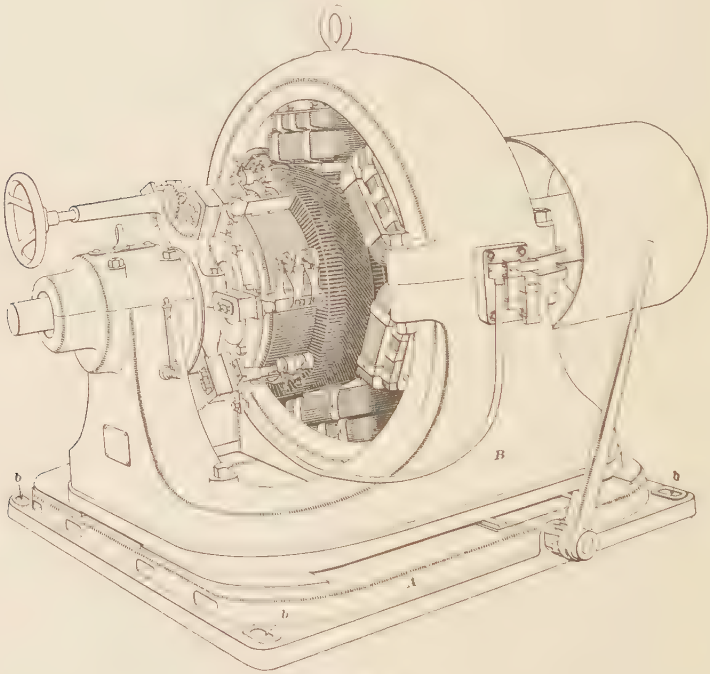


FIG. 2.

No man should try to assemble the parts of a heavy machine without being provided with the rigging devices adapted to the work. Large stations provided with large units are generally equipped with cranes to replace armatures or fields that may become burned out. Small stations are not so well fixed, so the installer must usually look them up for himself. As the construction of machines varies to some extent, so must the method of handling the parts. In

order to be specific, the machine shown in Fig. 2 will be taken as the one to be assembled. This is a six-pole belt-driven street-railway generator of the Westinghouse type. The bedplate *A* and the lower half of the machine *B* are worked on to the foundation by means of crowbars and rollers; as the wooden sub-frame projects above the level of the floor, a false wood floor must sometimes be laid. The bed-plate is then worked into such a position that the holes *b*, *b* in the four corners of the foot flange fall just over the bolts or bolt holes that they are intended to engage. The blocking is then taken out and the machine let down upon the foundation or frame, as the case may be.

4. The next step is to place in position and connect together the bottom field coils *c*, *c*; the field coils may be put in the top half of the frame at the same time, so that this part can be swung into position as soon as the armature is in place. Great care must be taken that the coils are slipped over the pole pieces with proper regard for the marked ends, or trouble will surely result. Field coils that do not weigh more than 200 pounds may be safely lifted into place, but great care must be taken not to bruise the insulation or bend or break the terminals. For handling heavier coils than this, and also for handling the armature and top half of the frame, tackle must be rigged immediately above the foundation. In rigging this tackle, the total height that the top half of the frame must be lifted to get it in place after the armature is in position must be considered. If a chain hoist must be used, do not attempt to lift a 4,000-pound armature or top field half with a 2,000-pound hoist—use a 4,000-pound hoist, or even two 2,000-pound hoists. To support the hoist, a rope is slung in several turns from a roof girder or from a crosspiece laid between two girders. Old cloth or carpet is interposed between the rope and the girder so that the former may run no chance of being cut. The hoist is hung at such a height as will enable its full hoisting range to be utilized. If in spite of all that can be done, the hoist does not have sufficient range for the highest

lift, the lift will have to be divided into two stages. These two stages must be such that the end of the first lift leaves the part to be lifted as near to the floor as possible. The part is then securely blocked, the point of support of the hoist raised, and the lift completed. To put the armature in place, it is moved as close as possible to the machine, so that its tendency to swing in, due to its being out of the vertical line of the hoist, will be a minimum. This tendency must be further offset by means of a strain put on by a block and tackle or hand line applied at the side. The bearing parts of the armature shaft should be encased in cloth before lifting, to avoid nicks and dents. The pillow-blocks should be inspected to see that they contain no iron filings or other dirt, and should then be filled with a good quality of oil.

5. Under no circumstances should any of the weight of the armature be supported by any device in contact with the commutator; the point of support should always be the shaft. For handling small armatures whose pillow-blocks are removable, a couple of ordinary handle bars, such as

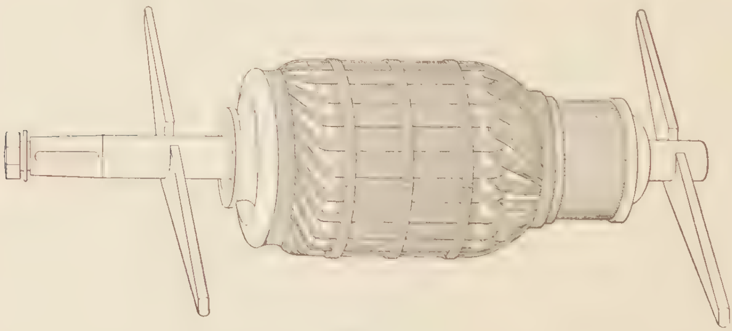


FIG. 3.

those shown in Fig. 3, should be used, and for the heavier ones a rope sling S and spread bar B such as are shown in Fig. 4; note that the rope is crossed on itself when it passes through the hook. When handling a heavy armature, its commutator should be protected by a blanket or other padding to save it from knocks that may dent a bar or damage

a band; the armature should not be rolled over the floor carelessly, as a nail head or a piece of hard matter of any kind in its path is liable to nick a band wire, so that as soon as the machine is up to speed and heated, causing some expansion, the band wire will break. As soon as the armature is swung over its final position, the shaft is wiped off with clean waste and served with a thin film of good cylinder oil. The bearings are then slipped on; in doing this, the oil rings must be lifted by running a clean round rod or stick in the end, otherwise the end of the shaft may jam

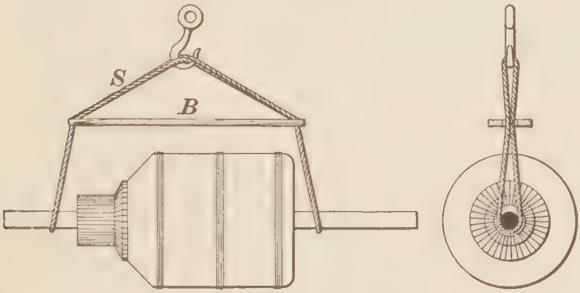


FIG. 4.

one of the rings and bend or break it. Where spiral bearings are used, care must be taken to put them on the shaft as the marks call for, otherwise the oil will be fed out instead of in, and the box will run hot. All these points being looked after, the armature is dropped into place and given a few turns by hand to see that the oil rings work and that there is enough end play to prevent binding. Using the pulley end of the shaft as a straightedge, the machine is now leveled by means of a spirit level, split sheet-iron washers being put under the bedplate around the anchor bolts if one end must be raised.

6. If the foundation and frame have been well made, little or no lining will be called for. With the armature in place, the top half of the frame, whose field coils have been previously connected, is lifted on. The joint between the top and bottom halves should be well cleaned before setting

them together; it may be necessary to wipe off some white lead, put there to prevent rust, or to surface down a dent due to a falling tool. Where the machine has detachable pole pieces, the same care should be exercised in regard to the surfaces between them and their seats on the frame. When the top half is in place, the pulley is put on, the machine lined up to the engine that is to drive it or to the pulley that it is to drive, and the yoke, brush holders, and other fittings put on. The driving belt should have a cemented, not a laced, joint. It must be borne in mind that in order to make a good job of lining up the motor or dynamo, it is necessary that the device to which it is to be belted has been installed with the same care as the dynamo itself.

7. Starting Up.—If the machine is a dynamo, it is, of course, started up by means of its engine; if a motor, current from the line must be used. In either case, be sure that there are no tools or other parts lying on the belt or on the dynamo where they can shake off on to the armature or be sucked up by the fields. The machine should be run at about half speed for an hour or more to give bad bearings a chance to show their presence and to see that the oil rings do not stick. If all the parts of the machine seem to be in good working order, the speed can be run up to its normal rate, and the machine given a chance to pick up its field, but no load should be put on for several hours. Where the parts of a machine have been exposed and are damp, the insulation will be low, and arrangements should be made to bake the windings with current at low voltage, so that there may be no risk of a burn-out at the start; but in testing the insulation of a machine that is running on a grounded circuit, such as a street-railway circuit, unless the permanent ground is removed, the insulation will, of course, show a dead ground.

8. The machine should be turned over very slowly at first, so that in case it is not lined up exactly right the belt will not run off before the necessary change can be made; should the belt try to come off, it can, as a rule, be held on with a

bar until the machine can be stopped; even if the belt does come off on the *outside* of the pulley, no special harm is done; but if it comes off *inside* of the pulley, it is liable to have one of its edges curled and stretched and it will give constant trouble afterwards. On this account, it is a good plan, if there is any doubt as to whether the pulleys are in line, to cant the machine pulley a little in favor of the outer edge.

9. In order for a dynamo to pick up its field, it is necessary that the fields have a little residual magnetism left over from the last charge. Electric machines, except some of the largest sizes, are always tested under load before they leave the factory, and, as a rule, retain enough of the magnetism to "pick up" on when they are installed. But sometimes on the way from the factory to their destination this magnetism is not only vibrated out of them, but in some cases the vibration has been known to reverse the polarity of the dynamos. Even machines in service a long time lose or reverse their residual magnetism for no apparent reason. In such cases, the fields must be recharged. In the case of an isolated machine, this recharging must be done from a battery, unless there is some other machine in the neighborhood that can be temporarily tapped to the outside line; where there is more than one machine, the field of the dead one can be charged from the live one; in such a case, the field leads must be either disconnected or the brushes lifted off the commutator of the dead one, to avoid running it as a motor. Of course, in the case of a motor, the field current is supplied from the line, so that with motors there is no trouble on account of the fields losing their magnetism.

OPERATION.

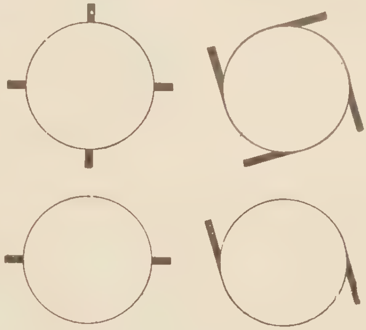
10. General Care of the Machinery.—The dynamo or motor and all devices connected with its operation or regulation should be kept perfectly clean. No copper or carbon dust should be allowed to accumulate to cause breakdowns in insulation. The oil gauges and grooves should be

kept in working order and the oil in the wells should be renewed at regular intervals. The brushes should be kept clean. They should be set and trimmed to fit the commutator, and copper brushes should be taken out once in a while, whenever they become clogged, and dipped in gasoline to cleanse them. When a machine is shut down, copper brushes should always be lifted just before the dynamo comes to a stop and they should not be let down until the machine, if a dynamo, is under headway again. New carbon brushes should be sandpapered to fit the commutator, by sliding a piece of sandpaper back and forth between them and the commutator. Do not use emery paper for cleaning the commutator, as emery is more or less of a conductor and may cause short-circuiting between the bars; also small pieces of emery become lodged in the brushes and scratch the commutator. The connections and all setscrews and bolts should be inspected regularly to see that none are liable to become loose and fall out. All screws that secure shunt-field or rheostat wires should be fixed by a drop of solder.

Oil should be used very sparingly, if at all, on the commutator; to lubricate it, put a film of vaseline on a canvas cloth, fold the cloth once, and let the commutator get only what goes through the pores. Never allow a loose article of any kind to lie on any part of a machine. Oil cans should be made of brass so that they will not be attracted by the pole pieces. Do not allow a belt to run tight enough to cause a hot box, nor let it run so loose as to squeak and threaten to come off. When closing a switch, do not tap it in to see if everything is all right, but once the mind is made up that everything is as it should be, close the switch firmly. The operator's eyes and hands are of more importance and value than anything else in the station. If there is any doubt about whether a switch should be closed or not, do not close it until all doubt is removed. All switches should be left open when the machine is not in action. Circuit-breakers should be tried at frequent intervals to see that they are not stuck or set for the wrong load.

BRUSHES.

11. On direct-current machines, the brushes and commutator require, perhaps, more attention than all the other parts of the machine put together. Brushes should in the first place be of sufficient size to carry the full-load current of the machine without heating. Brushes are of two kinds: *radial* and *tangential;* **radial brushes** point straight at the center of the circle that represents the outline of the commutator; their direction is parallel to the radius, as shown in Fig. 5 (*a*). **Tangential brushes**, Fig. 5 (*b*), are generally made of copper and are found, as a rule, on lighting machines. Radial brushes are made of carbon and are mostly found on power machines, though they are now largely used on lighting machines as well. Carbon brushes are used on machines whose output is at a comparatively high voltage, and, hence, low current; copper brushes, on machines of high current and low voltage. Also, carbon radial brushes are used on machines that must admit of being reversed in rotation. Carbon brushes are generally found on machines subjected to sudden and violent variations of load, while copper brushes are better adapted to conditions of slowly varying or constant load. Carbon brushes are usually copper plated to within $\frac{1}{4}$ inch or $\frac{1}{2}$ inch of their bearing ends, in order to give them better contact with the brush holders. Also, carbon brushes often contain a lubricant in the form of the paraffin with which the carbon dust is treated in the course of its manufacture, so that these brushes being self-lubricating, no compound or grease is needed on the commutator itself. With carbon brushes, the commutator takes on a dark-chocolate polish and the brushes emit a squeaking noise at starting or stopping.



(a) (b)

FIG. 5.

12. Carbon brushes are made in several grades of hardness, adapted to different conditions of working and different kinds of commutators. In stationary, direct-current work, soft carbon is used; on street-car work, hard carbon. Carbon has the great advantage that, being of relatively high resistance, it limits the value of the current generated in the coils that are short-circuited as they pass under the brushes and thereby reduces the sparking. By reason of this fact, carbon brushes admit of a wide variation in the load and hence in their non-sparking positions, without giving any trouble. This is why carbon brushes are used on high-voltage dynamos where there are sudden and violent changes that cannot be met by shifting the brushes. With copper brushes it is different; copper is of such low resistance that the short-circuited coil passing under a brush generates sufficient voltage to force a large current that causes sparking through the local circuit comprising the coil, two commutator bars, and the brush. This condition occurs if a variation in the load leaves the brushes out of the non-sparking points, so that copper brushes must, as a rule, be shifted to meet any variations in the load. Many kinds of copper brushes have been devised to meet this objection; in every case the object has been to increase the resistance in the path of the short-circuited coil without increasing the resistance to be traversed by the main current of the machine. To this end, brushes have been made of alternate layers of copper and of carbon, or have been made of copper wires or gauze.

In Fig. 6, A is the ring armature of a dynamo sending a current through lamps L by way of brushes $a+$, $a-$; coils c, c are passing under the brushes and are, therefore, being short-circuited by them through the local loops, *1–2–3–4–5–6–7*. It is not hard to see that if the center of the brush throughout its width be made of an insulating material, as indicated by the dotted lines, the local current due to the short-circuited coil cannot get from the heel of the brush to the toe, or *vice versa*, without first flowing up and down the full length of the brush, so that the short-circuited

coil cannot generate so large a current, although the flow of the current in the main circuit of armature and lamps is not interrupted On account of its decreasing the capacity of the brush, and for other reasons, it is not desirable to break the short local circuit, but a compromise is made by constructing the brush of alternate layers of copper and

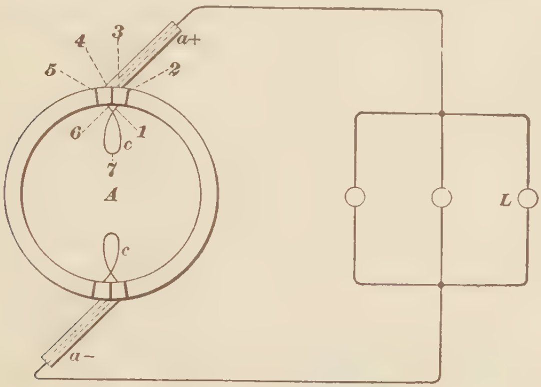


FIG. 6.

carbon or some metal whose specific resistance is high enough to reduce the current in the short-circuited coil, but not high enough to offer any serious impediment to the flow of the main current. Copper brushes are never made solid; they are made flexible, in one way or another, so that they may more readily conform to the surface of the commutator and bear at as many points as possible.

13. Ordinary copper brushes are not strictly tangential, this type being used only on small machines and on arc-light machines where the current is small. A form of strictly tangential brush is shown in Fig. 7 (*a*). Carbon brushes are often made as a kind of compromise between the tangential and the radial types, as shown in Fig. 7 (*b*). Just as in the case of the most common form of copper brush, it is neither exactly perpendicular nor parallel to a radius of the circle representing the end view of the commutator. No matter what style of brush is used, it should

bear against the commutator with the proper tension. All generator brushes and stationary-motor brushes are so arranged that the tension can be regulated. Portable motors (street-railway motors) are not so fortunate. They are so limited in point of space and accessibility that the brush-holding device must be designed to average the right tension throughout the life of the brush.

The tension that a brush spring must have depends on the material and condition of the commutator and on the material of the brush itself. A copper brush does not, as a rule, call for as much tension as a carbon brush, and soft carbon will run with less tension than hard carbon; a rough commutator needs more brush tension than a smooth one; for given brush contact, large currents call for more pressure than small ones. Finally, where there are several brushes in each holder, the tension must be the same on all, so that they will all take about the same current. This tension should be great enough to pass the current without sparking or heating, but it should not be great enough to wear out the commutator unnecessarily. One of the features most conducive to success with brushes is the proper setting of them; this subject will be taken up in the article on "Sparking."

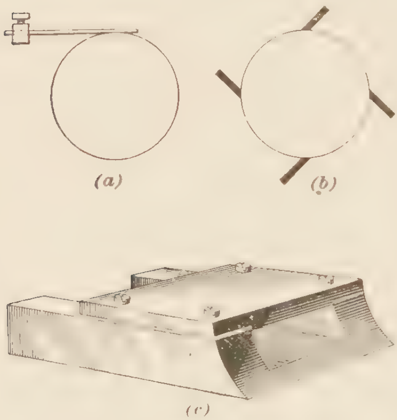


FIG. 7.

If the contact between the brush and the commutator is loose, the contact resistance will be high and heating will result. On the other hand, increasing the pressure beyond a certain amount results in very little reduction of resistance, but greatly increases the friction. For stationary work, a pressure of 2 to $2\frac{1}{2}$ pounds per square inch of brush contact surface should be sufficient. For railway work, the pressure

has to be much heavier on account of the jarring to which the motor is subjected.

14. One of the greatest weaknesses of carbon brushes is that they, at times, stick in the holder so that the tension spring is not strong enough to force down the brush to its place, and even if it does force it down, the pressure on the commutator will be too light. This very serious fault may be due to either of two causes: lack of uniformity in the thickness of the brush or an excess of paraffin in the brush. If a brush is thicker at one end than it is at the other, it may go into the holder freely if put in thin end first, and might not go in at all on the thick end. The result of this is that as soon as the brush wears down to a point where the thick end enters the holder it sticks. On the other hand, the fault may be due to a nick or burr in the brush holder itself. The only way to get rid of all chance of such trouble is to have a hard-steel gauge for the brushes and another for the holders; discard all brushes that will not pass through the brush gauge freely and file out any holder that will not take the holder plug gauge. As a final check against a bad brush getting into use, always try the brush in the holder end for end. The common practice of sandpapering a brush to get it in is a very bad one, as it not only makes the brush lopsided, thereby impairing its contact with the main surface in the holder, but it also takes off the copper plating.

The second source of trouble—an excess of paraffin in the brush—is accounted for as follows: If a carbon brush is snugly fitted into the holder so that it slides back and forth freely, but without any clearance, while the holder and brush are cold, as soon as they become warm the paraffin oozes out, forms a paste with whatever carbon or copper dust there may be present, and causes the brush to stick. It is a very common occurrence to see brushes that have been giving trouble coated with a tough skin of carbon dust and paraffin that can be readily scraped off with a knife. It is very essential that the brushes should be kept clean and trimmed to fit the commutator; to trim them, an iron

jig similar to that shown in Fig. 7 (*c*) should be used so that the bevel may be kept perfectly true. This jig is intended more particularly for filing copper brushes. Carbon brushes can be sandpapered to shape in place.

THE COMMUTATOR.

15. The **commutator** is the most sensitive part of a machine and its faults are liable to develop more quickly than those of any other part. When a commutator is in the best possible condition, it becomes a dark-chocolate color, is smooth, or glazed, to the touch, and causes the brushes, if of carbon, to emit a characteristic, squeaky noise when the machine is turning slowly. Under no circumstances should any weight be allowed to rest upon the commutator, nor should it be caught with a sling when the armature is being lifted. The commutator should preferably be set upon a tapered seat on the shaft, forced up to its seat, and secured with a nut and lock, besides being provided with a key to prevent turning. With such an arrangement, the problem of putting on or taking off a commutator is very much simplified. Great care should be taken to eliminate every possibility of the device becoming loose, as such a defect gives rise to others, among which can be named open-circuited leads and consequent sparking. Great care should be taken to secure the best insulation between the bars and the shell, and from bar to bar, as a breakdown in the commutator insulation has the same effect as a breakdown in the insulation of the armature winding itself. The commutator bars should be perpendicular to a plane at right angles to the shaft, so that the brushes will not, in effect, set on a diagonal and cover more bars than they should. To secure the best results, the brush holders should be set as close to the commutator as possible, so as to do away with chattering. This is most desirable on machines that are to run in both directions, and the brush holder should, on such machines, be designed to slide radially

inwards, so that wear in the commutator can always be readily compensated for.

16. If a dynamo or motor is not abused with too much overload, if the brushes are set properly, and if the commutator is made of the proper material, it should seldom get rough. As a rule, sandpaper and emery cloth are used around machines much more than they should be. For ordinary roughness of the commutator, due to some temporary abnormal condition, it is well enough to use sandpaper, but for chronic roughness some more permanent cure must be applied, as there is some serious cause behind the trouble. Take any of the following troubles, for example:

If a commutator, when it is built, is not properly baked or screwed down after it is baked, it is liable to bulge out in the course of time under the action of the heat due to its normal load and the centrifugal force, or it may develop loose bars. In the case of the bulging of one side, sandpaper will not do any good, because from the nature of the way in which it must be applied, the low part gets as much sandpapering as the high part and the relation between the two is kept the same. The best thing to do with a commutator that bulges badly is to take it off, bake it so as to loosen the insulation, tighten it up well, and turn it off in the lathe. For ordinary curvatures of surface, that is, unevenness due to wear, it is customary to set up a tool post and slide rest on the bedplate of the machine itself and turn off the commutator in position.

If the machine is a dynamo, it is run from its engine, which must be run very slowly; if the machine is a motor, its speed must be cut down by putting a water resistance in series with the armature but not with the field; in either case, a tool with a diamond-shape point must be used and the speed must be such that the bars will not be burred nor the nose of the tool burned. Keep the cutting point just about opposite (but a trifle above rather than below) the center of the commutator. After the commutator is turned, it should be smoothed off with a file and sandpaper, any

burrs between the bars should be picked out, and vaseline sparingly applied through the pores of a coarse canvas rag. Always have the brushes raised when sandpapering a commutator, even if the machine has to be given a start and allowed to run on its own momentum, because, otherwise, the brushes will catch all the dust, with the result that they are apt to get clogged or the commutator become scratched. Outside of this, it is dangerous to sandpaper a machine that runs with an excited field and at a high speed, because the flying copper dust might be the cause of a short circuit that will burn the operator. This has happened more than once.

A narrow scratch or several of them all around the commutator means that there are particles of hard foreign matter under one or more of the brushes; the best thing to do is to take out the brushes and clean them. A broad scratch around the bearing surface of the commutator probably means that one of the brush holders has been set too close or has become loose and slipped down to a point where it touches the bars. The same scratchy appearance around the ears of the bars probably means that the armature has too much end play or that one of the brush holders is set over too far.

17. High Bars.—A metallic click emitted twice, four times, or six times (according to the number of brush holders in use) per revolution, indicates a high bar in the commutator; in such a case, the brushes will be seen to jump a little when the high bar passes under them. A high bar can come about in either of two ways: it may be due either to a loose bar working out or to the fact that one bar is much harder than any of its neighbors, and, therefore, does not wear down at the same rate. If the high bar seems to be firm under a blow from a hammer, it will be safe to take it down with a file while the armature stands still; but if the hammer test proves the bar to be floating, it is a serious matter, and nothing short of a regular repair job will give satisfaction. In testing a bar or bars with the hammer, care must be taken not to nick or dent the commutator, as

such a defacement will cause the high-bar click to be emitted and it will be misleading.

18. Low Bars.—A fault very much akin to a high bar but much more serious in most cases, is the low bar, which gives forth very much the same sound, but the brushes drop, instead of rising, as the fault passes under them. The low-bar trouble may be due to any of several causes: it may be due to the commutator having received a severe blow in the course of handling; to one or more bars being of poorer material than the rest; or it may be due to the gradual eating away of the bar on account of sparking at that particular place. On any but ordinary bipolar machines, a loose connection will generally affect more than one bar. The main difference between a high bar and a low one is in the amount of work required to remedy them. A high bar can be removed by filing down or turning down that bar alone to the level of the others, but to get rid of a low bar, the rest of the commutator must be brought down to its level. This means that unless the low bar or flat is very slight, the commutator must be turned off. There are several other faults pertaining to commutators that will be taken up under the head of "Sparking."

19. Of course the most serious condition is to have a commutator that is poorly made and of poor stock. If the mica and copper used are not of the proper relative hardness, one will wear down faster than the other, leaving the surface of the commutator a succession of ribs. If the mica is too soft, it will pit out between the bars, leaving a trough to fill up with carbon dust and in a degree short-circuit the

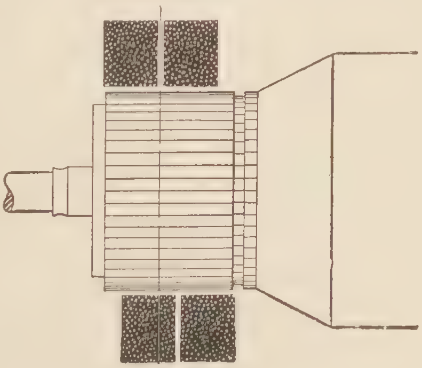


FIG. 8.

neighboring armature coils. If the mica bodies are too hard or too thick, the bars will wear in ruts and call for frequent turning down. The best combination for all-round work is made of soft, clear mica and hard-drawn copper. One practice of the day, and one that tends to materially increase the life of a commutator, is to so design the shape of the commutator bars and the set of the brushes, and to so proportion the end play of the armature that the brushes will play over the whole wearing surface of the commutator.

Fig. 8 shows such a disposal of the brushes, which are said to be **staggered.** The plan is to have the brushes so disposed that no ridges can be formed either on the outside edges or center of the commutator.

THE ARMATURE.

20. Armatures should be handled with great care, as it is an easy matter to bruise a coil or a lead, and this may not be noticed until the machine is started up and the trouble begins. All armatures should be supported by their shafts as much as possible, and should not be rolled around on the floor at the risk of having a coil punctured or a lead broken. When lying on the floor, they should lie upon padding of some sort. Extra armatures not in use should be kept housed in a dry place. The bearings and end play of the armature in use should be closely watched so that the core may not be let down on the pole pieces.

21. Heating of Armatures.—An armature should run without excessive heating; if it heats so as to give off an odor, any of several things may be the matter with it. It may be damp—a condition that, as a rule, is shown by steaming, but which can be better determined by measuring the insulation to the shaft with a voltmeter. This insulation should be at least 500,000 ohms when the machine is hot. If less than this, the armature should be baked, either in an oven or by means of a current passed through it in series with a lamp bank or water resistance. In using

a water rheostat watch it closely, for the current increases as the water becomes hot. The baking current should not exceed the full-load current of the machine. In applying the current to the armature, be sure that the series field, if the machine has one, is not included in the circuit, and that the shunt field is broken; for if either field is on, the machine may start up as a motor. A machine that is too damp to run will heat at no load as well as at full load.

22. Another cause of heating under no load is due to the commutator being partially short-circuited all around from bar to bar, so that even when the coils are in the most active part of the field, a strong current can be set up through the local circuit provided by the coils themselves, the commutator bars to which their ends are attached, and the defective insulation between these bars. Such a condition often arises on an old machine, where the oil applied to the commutator has soaked into the mica bodies and carbonized. There is a case on record where the commutator was so short-circuited in this way that the machine would not start as a motor, because the applied current passed through the commutator instead of through the armature coils. The only true remedy for such a trouble is to put on a good commutator. Temporary relief can sometimes be obtained by taking a deep cut off the commutator, thereby removing the most defective part of the insulation.

23. If instead of the whole armature running hot, the heat is confined to one or two coils, the indications are that there is a short circuit either in a coil or between the two commutator bars that the ends of the coil connect. Such a short-circuited coil run in a fully excited field will soon burn itself out. A short circuit of this kind can be readily detected by holding an iron nail or a pocket knife up to the head of the armature while it is running in a field; any existing short circuits in the coils or commutator will cause the piece of metal to vibrate very perceptibly. One or more coil connections reversed on one side of the armature will, on

a dynamo, cause a local current to flow from the strong half to the weaker half, and thereby cause all the coils to heat more than they should, besides decreasing the effective E. M. F. of the machine. On a motor, the effect is to decrease its counter E. M. F. so that it will take more current under given conditions, while the side containing the reversed coils will be hotter than the other side. The test for such a condition is to pass a current into the coils, one at a time, through the commutator bars, and to hold a compass needle over the coil that is connected to the two bars being fed; as soon as the reversed coils are reached, the compass needle will reverse the direction of its deflection. The coils must be disconnected and their ends reversed.

24. A broken armature lead or an open-circuited coil soon declares itself by causing a spark to travel around the commutator. A grinding, rumbling noise accompanied by excessive sparking and perhaps some slipping of the belt indicate that the bearings have worn down, letting the armature rub on the pole pieces. This is a trouble that takes place too often, and there is no excuse for it, for even if one does not know how long a set of bearings should run, he can easily tell how much wear has taken place by gauging the distances between the armature core and the top and bottom pole pieces. In such a case, the whole surface of the armature becomes hot and the bottom pole pieces and armature core show signs of abrasion.

25. An armature will sometimes get very warm through no fault of its own, but through heating from an abnormally hot bearing. Heat due to such a cause can generally be detected by the odor given off by the hot oil. Another serious trouble to which armatures are liable, especially motor armatures, is a bent shaft; this causes a very characteristic rattling noise to be emitted, the brushes spark, and the belt sometimes wabbles. The only thing to do with a bent shaft is to take out the armature and straighten its shaft. After straightening the shaft it may be necessary to

turn down the commutator before it will run true, as the bend in the shaft may have existed to a slight extent for several months.

26. One very peculiar fault to which armatures are liable is known as a **flying cross.** This is due to a loose wire that only gives trouble when the armature is in motion. The loose wire may either be broken, it may have a loose connection, or it may have defective insulation that allows it to come into contact with other wires as soon as the armature comes up to speed. In any case, the fault gives no trouble as long as the armature is at rest, but as soon as it gets up to speed, the centrifugal force throws the loose wire out of place and causes the brushes to flash. If not located and removed, the fault will, in time, burn a hole in the armature insulation.

27. Overloaded Armatures.—One of the most common causes of general trouble and heating in an armature is overload; this may be due to ignorance or neglect or to an error in the instrument that measures the load. There is a great tendency on the part of owners to gradually increase the load on a machine until it may be doing about twice the work it is intended to do. If the machine is a dynamo, lamps are added to its load one or two at a time; in this way it is an easy matter to overload a dynamo without intending to. If the machine is a motor, small devices may be put on it, one at a time, until an overload is the result. Another very common way of overloading a machine is to increase the voltage at which it is run. Many operators have the idea that as long as the current through the armature does not exceed its proper value, it does not matter what the voltage is, as long as it is not high enough to break down the insulation. The load on a machine is given by the product of the current and the voltage, hence the voltage has a direct influence on the load. If the voltage on a machine is doubled and the current is kept the same, the load on the machine is doubled. Therefore, in order to keep the

maximum load the same on a machine whose voltage has been raised, say 25 per cent., the maximum allowable current should be lowered 25 per cent. If the machine is rated at 100 volts and 50 amperes, and it is decided to run it at 125 volts, the current, to give the same load as before, should be 40 amperes. Where machines are running together in multiple, one may be taking more than its share of the load, due to poor equalization. Ammeters sometimes get out of order, read incorrectly, or stick; the needle may stay in one place while the load makes a change of 25 per cent., and the machine tender will be none the wiser.

28. When a dynamo is overloaded the commutator becomes rough, the brushes burn up and spark, the belt squeaks, and the machine grows hot all over. If it is possible to find a non-sparking point for the brushes at some intermediate load and at no load, this should also be possible at full load. If it is not possible, the symptoms point to overload and the ammeter should be tested. Of course, some machines spark badly no matter whether they are overloaded or not. This is specially true of the older types. When a machine persists in sparking when the commutator and everything else about it is in good condition, the trouble may generally be attributed to poor design. Some machines are so poorly designed that it is practically impossible to keep them from sparking.

FIELD COILS.

29. We generally have two kinds of **field coils** to deal with, namely, *shunt* and *series*, or both, depending on the style of machine. These may be further subdivided into two classes, form-wound and shell-wound. Fine-wire fields are usually called **shunt fields** because they form a shunt or bypath for the armature current on a dynamo or the line current on a motor; they are of high resistance, so that they will take but a small part of the current supplied to or by a machine, and they are subjected to the full line voltage.

as indicated in Fig. 9 (*a*), where *A* is the armature and *f* is the shunt field. Coarse-wire fields are usually called **series fields,** because they are in series with the armature, and should be able to carry the current that flows through the armature. They are of low resistance so that they may consume as little as possible of the voltage supplied to or by the machine, and as a result are subjected to but a small

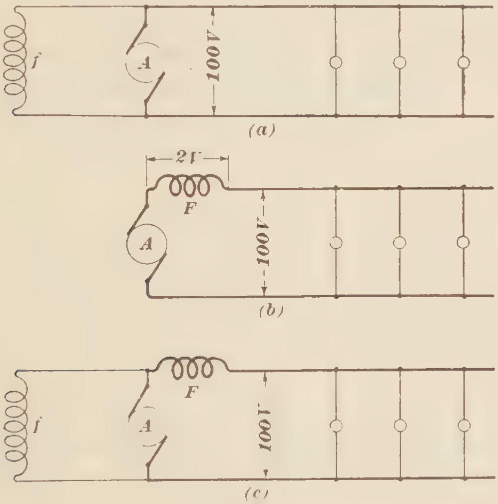


FIG. 9.

E. M. F., as indicated in Fig. 9 (*b*), where the drop through the series coils is supposed to be 2 volts. No matter what kind of field may have to be handled, the coils, leads, and connecting lugs should be handled with great care. The bearing surfaces of the coil should be brushed off before the coil is put in place, to avoid having any chips of foreign matter mashed into the insulation when the field bolts are screwed home.

30. Field coils should be installed in such a way that when the current passes through them, if one pole piece is called north, the poles on both sides of it will be south. Coils, as a rule, are marked so that the workman may know exactly

where they are to go and which end is to point toward the commutator. It is usually easy to tell by the shape of the field which face of it is to go next to the frame of the machine and which next to the armature. If the coils are not marked or if there is any doubt about the marks, the matter can be settled as follows: Set the field coils on the floor and line them up on edge, as shown in Fig. 10; connect them together and send a current through them. Get them, by trial, so that a piece of soft iron, held in the hand, will pass in an easy curve, as shown at *I*, from one coil to the other, the same end on. Should the piece of iron try to take the position shown at *I'* between any two coils, reverse one of them. When the coils are all turned so that the iron takes

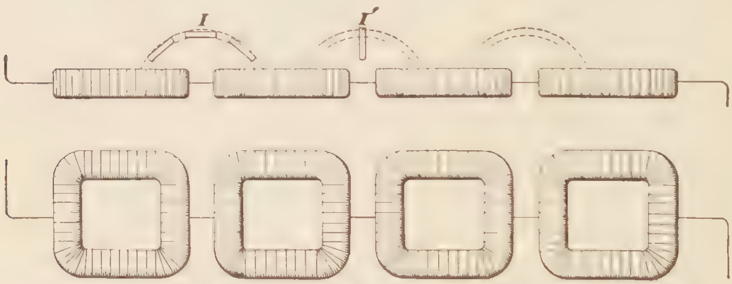


FIG. 10.

the curved path from one to the other, put them in place on the machine in this same relation, for then it is certain that they will alternate in polarity. A more certain test, perhaps, is to put the field coils into the machine as it is thought they should go (leaving out the armature), and test them with a compass or piece of soft iron the same as before. In using a compass, care must be taken that it does not stick, for then the lines of force of the field are liable to thread through it backwards and reverse its polarity; if this takes place just at the wrong time, it may be misleading. The reason for making the test without the armature in place is that the pole induced in the armature core opposite each pole piece is apt to influence the action of the compass.

31. The effect of putting a field coil in end for end on a dynamo is to decrease the voltage that it will generate even on open circuit, and perhaps render the machine unable to generate at all. On a motor, the effect is to greatly increase the current required to start, to abnormally increase the speed after it is started, and to cause the brushes to spark. If a motor has only two fields and one of them is connected incorrectly, the machine will either not start at all or else it will start very slowly and take a very large current. A two-field dynamo cannot generate, under the same conditions even if excited from some other source, unless one coil happens to be a little stronger than the other, in which case the machine might generate a small E. M. F.

32. Where the machine is compound-wound, the two windings generally occupy parts of the same spool. Great care should be taken to get both sections properly connected. On a dynamo, if the shunt field as a whole is connected correctly but the series field incorrectly, the machine will pick up its field and hold it, but it cannot be made to take a full load; for as soon as the main switch is closed and current goes through the reversed series coils, their magnetizing force partially neutralizes that of the shunt coil, reducing the E. M. F. of the dynamo and fixing a limit above which the load cannot be made go. If the shunt fields are wrongly connected and the series field are correctly connected, the machine will not pick up its field at all on open circuit, and whether it will or not on closed circuit depends on the resistance of that circuit. This resistance must be very low for the comparatively few turns of series field to pick up through it, and even if it did, the resulting voltage applied to the terminals of the wrongly connected shunt field would bring about a neutralization of magnetism, and the E. M. F. would fall again.

33. On a motor it does not matter so much whether or not the shunt and series fields, as a whole, are connected to assist or oppose each other, unless the machine has been

heavily over-compounded to run as a generator, in which case, if it is desired to use the series coils for maintaining constant speed under a variable load, it will be necessary to put a shunt in multiple with them. When a compound-wound motor is so connected that its series and shunt coils assist each other, it is said to be *accumulatively* connected, and it then has its greatest starting power for a given current. When the two fields oppose each other, the motor is said to be *differentially* connected, and if the strength of the two windings is in the proper relation, the speed of the motor will be constant within reasonable variations of load, if the voltage is constant. If, however, the series coils are too strong, the machine will run faster at full load than at no load, taking a great deal more current than it would with the reverse connection of the fields and perhaps sparking at the brushes.

34. Every dynamo, whether series, shunt, or compound-wound, must have its fields connected in a certain way, in relation to the armature and the direction of rotation, or it will not generate. The direction of rotation of a motor depends on the connection of its fields and armature, and it can be reversed by reversing either of these, but not both. When a motor runs in a certain direction, a certain relation exists between the directions of the currents in its armature and field; when either of these currents is reversed, it changes this relation and with it the direction of rotation; but when both are reversed, which corresponds simply to changing the polarity of the dynamo that runs the motor, the relation remains the same and so does the direction of rotation. Exchanging the places of the terminals applied to a motor (unless it is separately excited) will not change its direction of rotation. For given armature and field connections, a shunt machine will run in the same direction as a motor that it does as a dynamo; a series machine will run in the opposite direction in the two cases, while the direction in which a compound-wound machine will run as a motor depends on the relative strength of the two windings and on the conditions under which the motor is started.

FIELD-COIL TROUBLES.

35. Fields, like armatures, are subject to troubles of various kinds; they are liable to open circuits, short circuits, and grounds. An open circuit can give rise to various effects, depending on the conditions under which the machine operates and also on the style of machine. In the case of a series dynamo, an open circuit in the field will render it totally incapable of operating either as a motor or a dynamo, but no harm can come to the machine itself, unless the fault should take place while the current was on, in which case it would be apt to burn a hole in whatever happened to be around the break.

36. On a shunt machine, the amount of trouble caused by the opening of a field coil depends on whether the machine is a motor or a dynamo; and if a dynamo, on whether it runs alone or in multiple with other dynamos. If the machine is an isolated dynamo, a break in the field coil can do no further damage than to prevent the machine from generating and, hence, cut off the current from whatever lamps or motors may be operated by it. If, however, the dynamo is in multiple with other dynamos on the same load, the result of such a fault will be that the other machines will send a large rush of current back through the faulty machine and cause, practically, a short circuit.

37. Series dynamos are not, as a rule, run in multiple. If a shunt dynamo that is ordinarily run as a dynamo is made to run as a motor by current being backed through it, it will keep on running in the same direction, but will spark at the brushes, owing to the fact that the brushes are in a place suited to dynamo running and not to motor running. If the dynamo is compound-wound, the direction that it will try to run when it becomes a motor depends on the position of its brushes and mainly on the relative strength of the series windings and shunt windings. Breaking the field of a dynamo in multiple with other dynamos amounts to the same thing practically as breaking the field on a shunt motor.

Breaking the field of a shunt motor destroys its counter E. M. F., so that there is no opposition to the line E. M. F. and there is practically a short circuit through the armature. As the field magnetism dies down slowly, the counter E. M. F. dies down also, and the short circuit does not take place so quickly but that the faulty machine may acquire a very high rate of speed and throw its belt or do other damage before the fuse or circuit-breaker acts.

38. An open circuit in the field of a shunt motor in action, then, results in a short circuit, abnormal speed, throwing off the belt, and opening the circuit-breaker. On a compound-wound motor connected accumulatively, the speed will not reach such a high value, because the series coils hold it down; but if the motor is differentially connected, as soon as the shunt field breaks, the series coils opposed to it bring the motor to a stop and start it up in the opposite direction. If the fault should occur while the motor is standing still, it would be impossible to start a simple shunt motor with a safe current. A compound-wound motor will, if the starting current is large enough, start up on the field provided by the series-turns; but it will start up in the wrong direction if the series coils are so connected as to oppose the shunt coils.

39. The effect of the reversal of a single field coil on a machine depends on how many field coils the machine has, in other words, the more poles a machine has, the less will be the effect of an irregularity in one of them. If the machine has only two coils and one of them is incorrectly connected, the machine will not start as a motor and it will not generate as a dynamo. If there are four field coils, it will take a heavy current to start it as a motor, and the brushes will spark even while the motor is starting. As a dynamo, most machines will refuse to pick up their fields at all, except at very high speeds, and even if separately excited, the voltage at normal speed will be below its proper value. On machines of more than four field coils, the same

symptoms hold good, but to a less degree, and are characterized by sparking at the brushes that include the faulty field.

40. One other fault producing effects very much like the above is loose joints in the magnetic circuit. Where a machine has two halves fitting together, great care should be taken that no particles of foreign matter are allowed to get in the joint and so introduce an air gap into the magnetic circuit. The same precaution holds good in regard to machines having detachable pole pieces. The effect of a loose, or open, joint in the magnetic circuit, as in the case of a reversed field coil, is to weaken the field of the machine, so that on a dynamo there will be trouble picking up the field at normal speed, and the open-circuit voltage will be reduced by an amount dependent on the seriousness of the fault; while on a motor the starting current will be greater and the speed higher than it should be.

The effects are aggravated where the dynamo or motor is running in multiple with others. If a dynamo, it will be unable to meet the requirements of the rush hours, because its voltage cannot be increased enough to make it claim its share of the total load; it will require close hand regulation under varying loads, because its voltage will not vary at the same rate as that of its neighbors, although it may be the same kind of a machine. The best illustration of the condition applied to motors in multiple is found on an electrically propelled car where the two or more motors are practically rigidly connected within certain limits of load. The motors when doing their heaviest duty are in multiple, and the one whose path offers the least resistance takes the most current. The motor that has a reversed field coil or a loose, or open, joint in its steel frame, has a lower counter E. M. F., and hence has less apparent resistance; it will then be only a matter of time when this motor will cause the car to repeatedly blow its main fuse. The motor will become hotter than its mate, the brushes will spark, the commutator will blacken and become rough, the armature throw solder, and

a final inspection will probably show that all the cotton insulation on the field wire is baked or charred.

41. Short Circuits in Field.—The action of a short circuit in a field coil depends on the kind of machine, the manner in which the field coils are connected, and whether the short circuit is a good or bad contact. Take a shunt dynamo, with four field coils; if the coils are in series, as in Fig. 11 (*a*), so that the voltage across each coil is only one-fourth of the total voltage, a good short circuit in a single coil will cause it to run comparatively cool, while the remaining coils will get unusually warm. A bad contact is apt to emit more or less of an odor of burning shellac and other insulation. The cutting out of a single coil in four will reduce the resistance of the field circuit so that more current may flow through the remaining coils in an attempt to make up the loss of magnetism due to the cutting out of one coil, but this automatic compensation will not be so much but that the field rheostat resistance will have to be lessened to keep up the dynamo voltage.

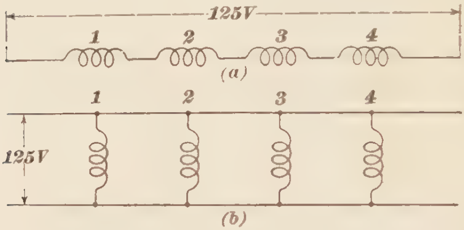


FIG. 11.

42. On the other hand, if the shunt coils are all in multiple, as shown in Fig. 11 (*b*), the faulty coil will be the one to get hot and the rest of the coils will run at normal temperature. If the fault is such as to cut out the coil entirely, the machine will loose its field, because a shunt machine will not support a field on short circuit. On a compound-wound dynamo running alone, a short circuit in the shunt winding will cause about the same symptoms, as far as the heating goes, as in a shunt machine. If the shunt coils are in multiple and connected as shown in Fig. 12 (*a*) (*short shunt* connection), the dynamo will drop its field if one shunt coil is dead short-circuited; but if the shunt coils, as a

whole, are connected as shown in Fig. 12 (*b*) (*long shunt* connection), so that the series coils are in series with the

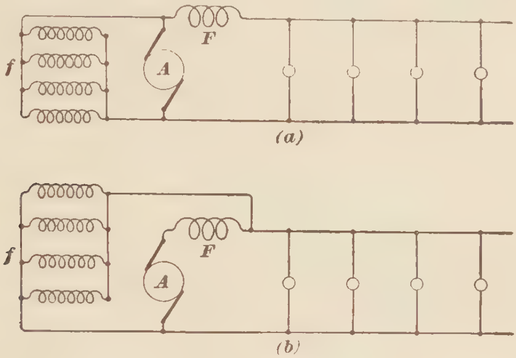


FIG. 12.

fault, the dynamo will throw its belt because the series coils work under the best possible conditions—a short circuit.

43. Moisture in Field Coils.—Moisture in field coils will cause them to heat and make the brushes spark. Before putting such fields into actual service, they should be baked out, either with the current or in an oven. Moist field coils, as a rule, steam when hot, feel moist to the hand, and their insulation to the frame of the machine measures low. The most refined way of locating a short-circuited field is to measure the resistance of the field suspected and compare it with that of a standard field of the same kind. A variation of over 10 per cent. should not be allowed, and where the fields are in multiple, not over 2 per cent. variation should be allowed. A short-circuited shunt field can be located by short-circuiting or cutting out one field coil at a time and measuring the open-circuit voltage of the dynamo.

44. Grounded Field Coils.—A grounded field is a very common source of trouble in some classes of work, but a very unusual one in others. Commercial circuits may be divided into two classes, namely, *metallic-return* and *ground-return circuits*. On metallic-return circuits, both the

outgoing and return wires are insulated from the earth. Ordinary lighting and conduit trolley systems are examples of metallic-return circuits. Ordinary street-railway systems are examples of a grounded circuit, since the trolley wire constitutes one side and the ground or track the other. The indications of a grounded field depend on whether the machine is on a metallic-return or a ground-return system, and if on the latter, whether the machine is a dynamo or motor and what place the field occupies in the circuit.

Metallic-return systems are, as a rule, characterized by having very little trouble from grounds; because, in the first place, since neither side of the system is permanently grounded, there is but half the tendency for either side to ground; and in the second place, a single ground does not at all disturb the operation of the devices, because another ground is necessary to complete the circuit. Should two grounds develop, one on each side of the circuit, or at two places in a device, a short circuit follows; but, as a rule, a single ground can be detected and removed before another occurs to cause trouble. Lightning is responsible for many of the grounds on metallic-return circuits. Inasmuch as ground troubles are more common on ground-return circuits, we will devote our limited space to this class of work.

45. Fig. 13 shows a shunt dynamo at work on a grounded circuit, the ground return being indicated by the dotted line. Suppose a ground takes place at *a*; the result will

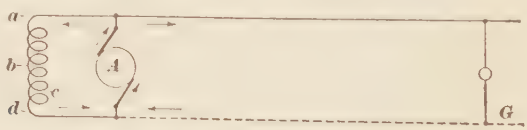


FIG. 13.

be a dead short circuit across the line, under which condition the dynamo will drop its field. A ground at *d* will have no effect, as that side of the circuit is already grounded. A ground anywhere between *a* and *d* will cut out a part of the field and severely heat the part not cut out.

46. Fig. 14 shows a compound-wound dynamo with the shunt field connected inside of the series field. A ground at *a* will cause the dynamo to drop its field as before; a ground at *d* will not be felt. A ground at *b* will cut out a part

FIG. 14.

of the field and the remaining part will heat badly; the voltage on the line will drop. Fig. 15 shows a compound-wound dynamo with the shunt connected across the terminals of the machine instead of across the brushes. This alters the conditions very much. A ground at *a* establishes a

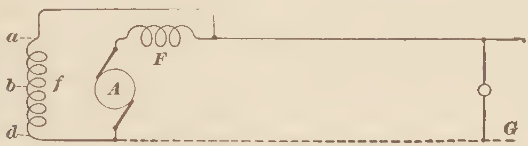


FIG. 15.

short circuit through the series field. The shunt field is cut out entirely and the line loses its power, but, owing to the strong current in the local circuit *A–F–a–d–A*, the dynamo throws its belt unless the circuit-breaker acts quickly. A ground at *b* will give the same indication as in the case of Fig. 14.

47. Fig. 16 shows a series dynamo at work on a grounded circuit. A ground anywhere on the field will cut the power off the line. A ground anywhere near *a*, unless the dynamo is of the arc-light type with very heavy armature reaction, will throw the belt. A ground anywhere near *b* will simply cut out the field and the machine will stop generating.

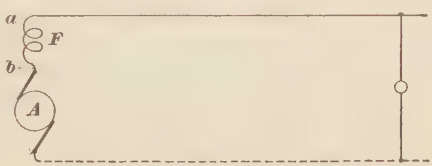


FIG. 16.

Fig. 17 shows a series machine as in Fig. 16, but with the field next to the ground. A ground at *a* will cause the dynamo to stop generating; a ground at *b* might cause it to drop its voltage and it might not, depending on the amount of resistance in the load; if this resistance is small, the dynamo will generate a lower voltage. A ground at *d* will not be felt.

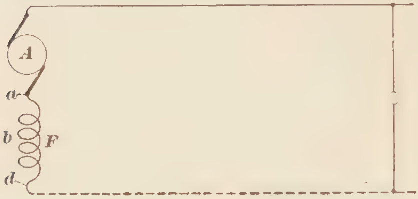


FIG. 17.

48. Let us suppose now that the dynamo in each of the above figures becomes a motor; the current, instead of coming from within the machine, comes to it from an outside source. In Fig. 13, then, a ground at *a* when the machine is running will cut out the motor so that it can get no power, the circuit-breaker will fly out or the motor will throw its belt, owing to the fact that in virtue of its momentum it will become a dynamo running on short circuit, both ends being grounded, one permanently and the other through the fault. The effects for the other grounds will be about the same as in the case of the dynamo.

In Fig. 14, a ground at *a* will cut out the shunt field and stop the motor very suddenly, as the armature will be grounded at both ends, and the series coils will be heavily charged by the current passing through the fault. The machine will really become a separately excited dynamo on short circuit. A ground at *b* will cause part of the field to heat badly, and a ground at *d* will have no effect.

In Fig. 15, a ground at *a* will cause practically the same action as in Fig. 14 and for about the same reason. In both cases, the motor will probably throw its belt. A ground at *b* and *d* will cause the same action as in the case of the dynamo.

In Fig. 16, a ground almost anywhere on the field, except at *a*, will separately excite a part of the field and bring the armature to a sudden stop, owing to its dynamo action

through the short circuit. A ground at *a* can cause no action of this kind, because the dynamo has no shunt field; and although the armature is permanently grounded on one end and is grounded through the whole series field on the other end, it cannot generate, because a series machine runs in opposite directions as dynamo and motor, for given connections; so that the direction in this case is not the right one. The motor of Fig. 16 finds its practical parallel in the street-railway motor as it is today. Fig. 17 is the same thing, only the fields are next to the ground, so that a ground in a field coil does not cut out the armature.

In Fig. 17, a ground at *a* cuts out the field and the entire short-circuit current passes through the armature, causing violent sparking that burns the brushes and commutator. A ground at *b* cuts out all the field below it, weakening the field and causing the armature to take an excessive amount of current. A ground at *d*, as in former cases, has no effect at all. Placing the field next to the ground has the disadvantage that a ground may take place in such a part of the field that the armature may be overloaded a long time before the fact is known; but it has the advantage that, being on the negative side of the armature, the difference of potential between the positive side of the field and the ground is very small, so that there is not as great a tendency for grounds to develop as in the first case. It is a well-known fact that cars equipped with motors whose fields are next to the ground give much less trouble from grounded fields than cars whose fields are next to the trolley.

REASONS FOR A DYNAMO FAILING TO GENERATE.

49. Loss of Residual Magnetism.—Among the many causes which may make a dynamo fail to generate, loss of residual magnetism is often one of the most troublesome. The magnetism that remains in the steel or iron frame after the field current is cut off is called **residual magnetism,** and every dynamo must have a certain amount of this to

start on before it can build up its field. As a rule, dynamos leaving the factory retain enough residual magnetism to start on, but there are several ways in which they can lose it; they sometimes lose it after having given no previous trouble of that sort in months or years. Some dynamos never lose their residual magnetism, or **charge**, as it is called, while others seem to have a weakness for doing it.

In many cases the peculiar action cannot be explained; in some cases it may be due to any of the following conditions: (*a*) Excessive vibration; hence, the dynamo should always rest on a solid foundation. (*b*) To the earth's magnetism; where practicable it may be well to set the machine so that its north pole is toward the north; then the earth's magnetism will pass through the machine in the same direction as its own. The earth's magnetism is very weak, but when assisted by vibration it may sometimes be sufficient to counteract the residual magnetism. Only two-pole machines can be really set to fill this condition, as on multipolar machines the poles radiate in all directions. (*c*) A dynamo set very near another dynamo; in such a case, stray lines of force from a loaded dynamo may thread their way through the magnetic circuit of an idle one in the reverse direction and neutralize its residual magnetism. (*d*) The fields accidentally given a slight flow of current in the wrong direction; this can very easily occur on a compound-wound or series dynamo, as current from the outside will always pass through the series coils in the opposite direction to that in which the current from the machine itself would pass. In shunt machines, however, this is not so, for as a motor, the field winding shunts both the armature and the line. (*e*) The machine started up with the fields or armature as a whole incorrectly connected, that is, reversed; in this case the result will be to destroy whatever residual magnetism there may have been. (*f*) The field circuit broken too suddenly; when a field circuit is suddenly broken, the residual magnetism is sometimes brought down to zero or even reversed.

50. Where a dynamo has lost its charge, the pole pieces will have little or no attraction for a piece of soft iron. There are several ways in which the charge may be restored. Series dynamos seldom lose their charge so entirely that they will fail to pick up a field on short circuit. Where a compound-wound dynamo refuses to pick up a field with its shunt field, it can often be made to pick up by disconnecting the shunt coils and short-circuiting the machine through a small fuse that will prevent damage due to the short circuit. The same idea in a modified form may be used on a plain shunt dynamo by temporarily connecting all the shunt coils in multiple instead of series. This makes the machine a series dynamo with a low-resistance circuit. Any machine can in many cases be made to pick up a field by simply short-circuiting the armature by holding a piece of copper wire across the brushes or by rocking the brushes back from their neutral position. The effect is to make the magnetism of the armature help the field to build up.

If none of these expedients produce the desired result, the fields must be recharged from an outside source. If the dynamo runs in multiple with other dynamos, this is an easy matter; it is only necessary to lift the brushes or disconnect one of the brush-holder cables on the dead machine and throw in the main-line switch, the same as if the machine were going into service with the others. The fields will then take a charge from the line and their polarity will be correct. After the field has been charged, the brushes or cable must not be moved until the main-line switch is open, because a short circuit will be made. If the dynamo does not run in multiple with another and there is a dynamo within wiring distance, disconnect the shunt field of the dead dynamo and connect it to the live circuit. The live circuit may be the trolley wire of a street-railway circuit. Bear in mind, however, that this is a 500-volt circuit, so that if it is to be used for charging 125-volt fields it must be applied for only a couple of seconds. There have been cases where it has been necessary to run a

couple of wires a quarter of a mile, or more, to obtain current for charging a field. If there are absolutely no other means available for charging, several cells of ordinary battery must be used; connect the field coils in series with the cells in series and give the pole pieces of the dynamo repeated knocks with a hammer while the charging is going on; if this fails, reverse the terminals of the battery and repeat the operation—it may be that the first time the battery is applied its magnetizing force opposes what little residue magnetism there may be in the iron. As a last resource, when all other available sources fail, connect the fields so as to obtain the least possible resistance, put them in series with the armature through a small fuse, and speed the armature considerably above the normal rate. Very often a dynamo, instead of losing its residual magnetism, will acquire one of a reversed polarity, due, perhaps, to the same causes exercised to a greater degree. Except where the dynamo is used for charging storage cells, or for electroplating, or for running arc lamps, or for running in parallel with other machines, the reversal of its polarity can do no harm. In case an arc machine is reversed, the concave carbon will be the bottom one and most of the light will be thrown up instead of down, where it is generally desired.

51. Wrong Connection of Field or Armature.—Every dynamo requires that a certain relation exist between the connection of its field and armature and its direction of rotation, or it will refuse to generate. Suppose a dynamo to be generating; if its field or armature connection (either, but not both) be reversed, it will be unable to generate; or if all the connections be left intact and the direction of rotation reversed, the machine will be rendered inert. Not only is it unable to generate with the wrong connections or rotation, but a short run under this condition will render the machine unable to generate after the conditions are corrected, unless the field is recharged, because the effect is to destroy its residual magnetism

Let us see why such is the case. It sometimes happens that when a dynamo is first started it has a small E. M. F. due to the residual field; but upon closing the field circuit, the E. M. F. falls to zero and the machine refuses to generate. Such action indicates a wrong connection of field or armature for the given direction of rotation and can be explained as follows: Suppose the dynamo to be properly connected and to be generating; this implies that the field current is in such a direction as to produce a magnetic field that reinforces the residual field. Now, without disturbing anything else, let the field terminals be reversed; for the sake of clearness, we will suppose that there remains a residual field due to the current last flowing. Under this condition, the lines of force due to the residual field are in the same direction as they were when the machine was properly connected and generating; the small current now generated in the armature, and due to the residual field, will be in the same direction as it was then, but the field connections being reversed, the current flows around the poles in such a direction as to neutralize their residual magnetism. The weak residual field is now opposed by this new field and soon the residual field is reduced to zero, thus totally depriving the machine of all ability to pick up. Nor can a reverse field, even if established by recharging, be maintained; for, assuming a reversed residual magnetism to be provided, the lines of force have changed direction, the armature current does likewise, and previous conditions being reestablished, the residual field is again destroyed. If, then, a dynamo fails to generate, and all other conditions are apparently correct, reverse the field leads and again try to make the dynamo generate. If a loss of residual magnetism is indicated by very weak poles, recharge the fields.

52. Open Circuits.—A series dynamo cannot, of course, pick up its field if any part of the circuit is open, for there is but one circuit. It cannot pick up its field if the resistance of its outside load is above a certain value peculiar to each machine, for as a rule series dynamos supply devices

that are also in series, and every device added means more resistance for the machine to pick up through. As it will not pick up through a high resistance, it is customary to provide series dynamos with a switch, by means of which the line and machine are short-circuited at starting, so that the load is not thrown on until the dynamo picks up, after which the short-circuiting switch is opened, leaving the line properly connected to its terminals. A shunt, or compound-wound, dynamo will not pick up if the shunt field circuit is open; the open circuit may be in the field itself, in the field rheostat, or in some of the wires or connections involved in the circuit. A careful inspection will generally disclose any fault that may exist in a wire or connection; to find out if the rheostat is at fault, short-circuit it with a piece of copper wire; if the dynamo generates with the rheostat cut out, the fault is in the rheostat. To find out if the open circuit is in a field coil, use a test-lamp circuit or a magneto-bell to test the coils one at a time. Before doing so, be certain that all communication is cut off between the machine under test and the line, if there are other machines on the same circuit. In making this test, bear in mind that if the dynamo is compound-wound and connected as shown in Fig. 15, an open circuit in the series coils will cut off the current from the shunt coils also.

Connecting wires, in course of time, are liable to be shaken loose or broken by vibration; they should be made of flexible cable, and the screws that hold them may be secured against turning by means of a drop of solder. A field circuit is sometimes held open by a defective field switch that, to all appearances, is all right; repeated burning will oxidize the tip of the blade and make a blister on it; the blister will not carry current and it will press the jaws of the switch apart so that only the blister touches, and so opens the circuit. Another trivial but common cause of open circuits is the blowing of fuses. Fuses of the enclosed type give more trouble in locating the fault than any other kind, because it cannot be told by looking at them whether the fuse is intact or not.

An open circuit in the armature will interfere with the proper generation of the current, but such a fault, as a rule, announces its own occurrence in a very emphatic manner and does not, therefore, require to be looked for. A very uncommon source of open circuit, where copper brushes are used, is due to the burning of the brush heels into oxide. The dynamo will refuse to pick up until the brushes are trimmed and cleaned. When an armature just from the factory refuses to generate where the one just taken out has been generating, the trouble is probably due to either of two causes: There may be shellac on the commutator—in this case, a little coarse sandpaper will set things right; the armature may be a right-hand armature while the one taken out was wound left-hand, or *vice versa*. The expressions right-hand and left-hand here apply to features of winding or connecting, and should such a condition arise, it can be remedied by reversing the armature or field connections, or the direction of rotation.

Before attributing the failure of a dynamo to generate to any of the above open-circuit causes, see that the brushes are on the commutator, the field switch closed, and the greater part of the field rheostat cut out.

Always bear in mind that the E. M. F. generated when a machine is started up is very small because the residual magnetism is weak. It may not require a complete open circuit in the field to prevent the machine picking up. A bad contact that might not interfere with the working of the machine when it is up to full voltage might be sufficient to prevent its picking up when started. A loose shunt wire in a binding post or a dirty commutator will introduce sufficient resistance to prevent the machine from operating. Trouble is very often experienced in making machines with carbon brushes pick up, especially if the brushes or commutator are at all greasy. If such is the case, thoroughly clean off the commutator, wipe off the ends of the brushes with benzine, and see that they make a good contact with the commutator surface. Metal brushes, if kept in good order, do not give

as much trouble as carbon in this respect, because their contact resistance is lower.

53. Short Circuits.—A short circuit on the line will make a shunt dynamo drop its field, but the dynamo may throw its belt before it does so. With a short circuit on the line, a shunt dynamo will not, therefore, pick up its field. Such a short circuit may be due to some fault in the pilot-lamp circuit, or it may be due to a motor switch being left in across the line by one of the outside consumers. On this account, it is to the interest of any company supplying power for motors to see that every motor is provided with an automatic cut-out, so that when the line voltage goes below a certain value the motor circuit will open. With a series or compound-wound dynamo, a short circuit on the line increases its ability to generate, because the fault is in series with the series coils and its large current passes through them. A series dynamo, like a shunt dynamo, will not pick up if the field is short-circuited. A compound-wound dynamo will not pick up on open circuit if the shunt field is short-circuited; it will pick up with an open circuit in the main circuit, but will not hold its voltage under load if the series coils are short-circuited. In some cases a shunt dynamo will not pick up on full load, as this realizes too nearly the condition of a short circuit; so that to be on the safe side, it is best to let the machine build up its field before closing the line switch.

Short circuits within the dynamo itself generally give rise to indications that point out the location and nature of the fault. In any event, the first thing to find out is whether the fault is in the dynamo or out on the line; if it will pick up its field when the line switch is opened, but fails to do so with it closed, the trouble is outside of the dynamo. It may be on the switchboard, where a workman may have left a tool or piece of wire lying across the bus-bars. The most common method used to get rid of a cross on the line is to burn it out; this is done by centralizing the

entire dynamo capacity of the station, if necessary, on the faulty circuit.

54. Brushes and Brush Holders.—In order for any direct-current dynamo to generate, its brushes must be in a certain position that depends on the type and design of the machine. As a rule, the design of the brush holder gives a clue as to where the brushes should sit, but one cannot say to a certainty where the brushes on a given dynamo should go unless he is familiar with that particular machine, because the position of the brushes is governed by conditions of winding and connecting not apparent to the eye. If the connections were brought straight out from the armature to the commutator bars, the brushes would always sit in line with the center of the space between the polar horns, because this is the position of the neutral field. But very often, for reasons of accessibility, the wires coming from the coils are given a **lead** that brings the normal position of the brushes in line with the centers of the pole pieces. The brushes on a motor sit the same as those on a dynamo, except that on a motor they are given a little lead backwards (in the opposite direction to that in which the armature rotates), while on a dynamo they are given a little lead forwards.

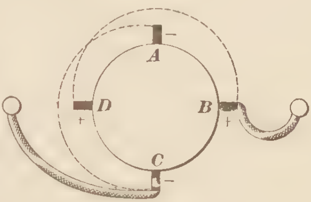


Fig. 18.

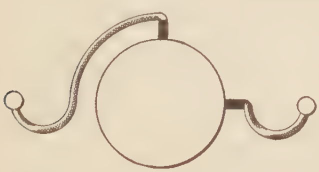


Fig. 19.

Fig. 18 refers to a four-pole machine with four brushes. The proper position for the brushes in this particular case is that shown in the diagram. *A* is on top, *B* to the right, *C* on the bottom, *D* to the left. If the rocker-arm be given a quarter turn to the right or left, so that, say, *A* takes the place of *B*, *B* the place of *C*, *C* the place of *D*, and *D* the place of *A*, it amounts to the same thing as reversing the armature cables or terminals, and the dynamo will refuse to generate.

Fig. 19 also refers to a four-pole armature, but it is so connected that only two sets of brushes are needed, and these two brushes are shown in the position where it is most natural to expect to find them. Fig. 20, however, shows where, for reasons of accessibility, symmetry, and safety, the brush holders are generally found in practice.

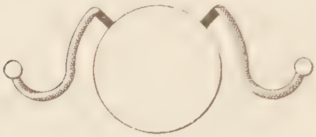


FIG. 20.

55. Field Coils Opposed.—Failure to generate may be due to one or more field coils being incorrectly put on, or connected, so that they oppose each other. The only thing to do is to locate the faulty coil and reverse its connection. On a compound-wound dynamo, the reversal of a shunt-field coil will generally keep the dynamo from picking up on open circuit, unless the dynamo has more than four coils; the more coils it has, the less effect has the reversal of a single coil. The reversal of a series coil is not felt until an attempt is made to load the machine; the voltage will not come up to where it should for a given load and the brushes are apt to spark on account of the weakening of the field.

56. Low Speed.—No dynamo will pick up its field below a certain speed, but with the field once established, the machine will hold it at a much lower speed than that required to establish it. The speed at which a series dynamo will pick up depends on the resistance of the external circuit.

57. Among the causes of failure to generate not included in the above are faults in the iron circuit, loose or open joints in the frame proper or between the pole pieces and the frame. Such imperfections also lower the maximum voltage of the dynamo. An armature core undersize or pole pieces bored out too large will cause the same trouble. There is one peculiar case on record where an extra armature was shipped from the factory and when put in the dynamo

refused to generate. The trouble was located in the armature core, which was found to be $\frac{5}{32}$ inch too small in diameter and an inch too short. The armature was given a running test before it left the factory, but it was run as a motor, and as no speed reading was taken, the mistake was not noticed. Occasionally orders become confused in the shipping department and the armature goes out with the wrong pulley; if the pulley is too large, the difference in speed will affect the picking up of the dynamo. Finally, it is possible to send out a 125-volt armature with 250-volt fields, or a 250-volt armature with 500-volt fields; in such a case it is only necessary to connect the fields in multiple to make the dynamo generate, if it should so happen that the voltage of the armature is the voltage wanted.

MOTOR FAILS TO START.

58. When a motor fails to start when the controlling switch is closed, any one of several things may be the matter. There may be an open circuit, a short circuit, a wrong connection, the power may be off the line, or the trouble may be purely mechanical. If the failure to start is due to an open circuit or to absence of power on the line, there will be no flash when the switch is closed and opened again. To tell if there is any power on the line, test with incandescent lamps or a voltmeter. If the fault is an open circuit, it may be found in any of the following places: Defective switch; broken wire or connection in the starting box; loose or open connection in some of the wiring; shellac on the commutator; a piece of foreign matter under one brush; brush stuck in the holder or no brush in it at all; brush springs up; fuse blown; some wire, apparently all right, broken inside of the insulation; or an open circuit in some part of the motor itself. Any of these sources of open circuit may be located with a magneto-bell or with a lamp or bell circuit. If the trouble is due to a short circuit, there will be a flash when the starting box is thrown off.

59. Among the more common sources of short circuit, are these: Short-circuited armature coils; short-circuited commutator; short-circuited field coils; field on a shunt or compound-wound motor connected so that the armature cuts out the field winding; carbonized brush yoke; brushes

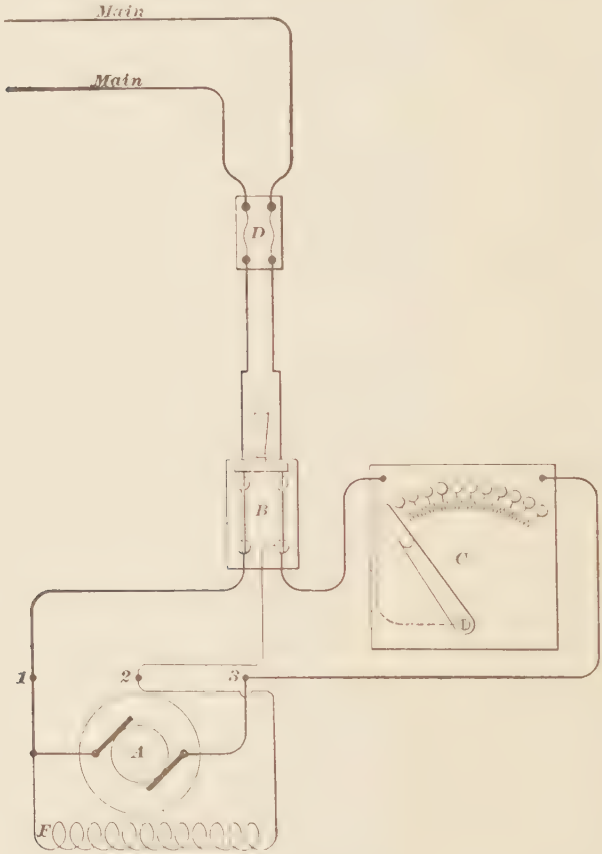


Fig. 21.

in the wrong position. If the armature coils or commutator are short-circuited, the machine may start and turn over part way and stop again. With a field coil short-circuited, the armature will start only under a heavy current, with accompanying sparking, and will acquire a high rate of speed.

60. Fig. 21 shows the correct method of connecting a shunt motor with an ordinary starting box. Shunt motors are usually equipped with three terminals, *1*, *2*, *3*. Terminal *1* takes one armature lead and one end of the shunt field; terminal *2* the other end of the shunt; and terminal *3* the other end of the armature. By examining the figure it will be seen that *2* is connected ahead of the rheostat, so that as soon as the main switch *B* is thrown in, the shunt field is excited from the mains. Then when the handle of *C* is moved from the off position to the first point, the current that flows through the armature has a strong field to react on and the motor starts up with a good torque. Fig. 22 shows the motor wrongly connected. In this case, the wire running from post *2* is connected between the rheostat and the motor instead of being connected between the main switch and the rheostat; in fact, it is equivalent to connecting posts *1* and *2* together. The result is that the shunt field is connected to the armature terminals and no current will flow through it until the starting-box lever is moved over. As soon as the starting-box lever is moved, current flows through the armature, but very little flows through the field because the pressure across the field terminals is only equal to the drop in the armature. The result is that the field is very weak and the motor refuses to start until the starting lever is moved so far over that a very large current flows through the armature. The box becomes excessively hot, and if the fuses or circuit-breaker do not give way, there is danger of something being burned out.

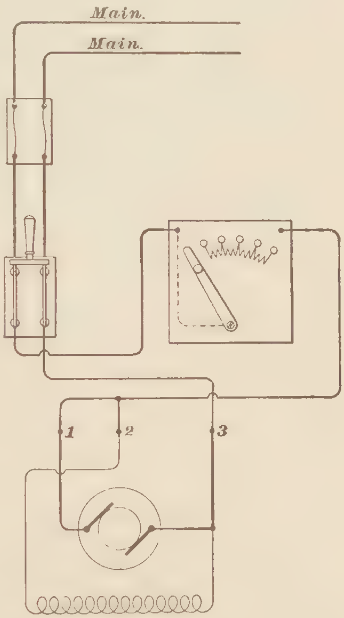


FIG. 22.

61. Wrong Motor Connections.—Wrong connections may be classed under two heads, *internal* and *external*. External wrong connections involve confusion of wires running to and from the motor, and are most likely to occur where a reverse switch must be used to change the direction of rotation of the armature. Such errors as getting an armature wire in where a field wire should go, or *vice versa*, come under this head. Where field and armature leads are of the same kind and are brought out through a closed motor frame, they should be felt out by hand, for this is where the confusion is most apt to take place. Wrong internal connections, as far as the man that assembles and sets up the motor is concerned, are confined to the field coils. If a motor has only two field coils and one of them is connected incorrectly, the motor will not start at all unless the starting current is so enormous that the armature itself magnetizes the field. If the motor has four coils and only one of them is incorrectly connected, the machine will start up under excessive current, but will spark badly and acquire a high rate of speed. Compound-wound motors with the series coils connected in to assist the shunt coils will not give the speed regulation that some classes of work require.

62. Mechanical Troubles.—Among the purely mechanical troubles that may interfere with the starting of a motor, the following may be mentioned: *Too much load; loose pole piece down on the core, or bearings worn until core is let down on the pole pieces; sprung armature shaft with the same result; hot box; tight belt; want of end play in the armature; some piece of foreign matter between the core and the pole piece, or between the pinion and the gear, if the motor is geared to its work.* In many cases, a motor can operate many more machines than it can start; it should be a rigidly enforced rule that all machine tools operated by the motor should have their shifters thrown over when the day's work is done. There is no excuse for an armature being let down on the pole pieces through wear in the bearings; they should be closely watched and close track kept of the time of last renewal. A loose

pole piece not only restrains the armature mechanically, but it weakens the motor field and lessens the starting power. A sprung armature shaft is liable to occur at any time, and may be due to a suddenly imposed overload, a sudden reversal, or a hot box. A bent shaft is visible to the eye and causes the machine to make a noise. It should be taken out at once. Want of end play may be the fault of the maker or of the operator; on every shaft there are two shoulders that take the thrust of the bearings and limit the end play. Sometimes an armature will turn freely when cold, but when it becomes hot and expands it will bind on the collars. The end play must be limited or there will be knocking, so that if in renewing a set of bearings longer ones are put in than were taken out, the end-play problem is liable to arise. Bearings should always be turned to gauge. Belts should be long enough to allow of sag in the slack side, which should run on top. This improves the area of pulley contact and lessens the tension required to prevent slipping.

SPARKING.

63. Sparking at the brushes may be due to any of the following causes : *Too much load; brushes improperly set; commutator rough or eccentric; brushes making poor contact; dirty brushes or commutator; too high speed; sprung armature shaft; low bearings; worn commutator; short-circuited or reversed armature coil; high-resistance brush; vibration; belt slipping; open-circuited armature; weak field; grounds.*

64. Too Much Load.—In this case the armature heats all over. The sparking may be lessened but not stopped by shifting the brushes ahead on a dynamo and back on a motor. If the machine is a motor, the speed will be low; if a dynamo, the voltage will be below the normal amount. In both cases the pulley is apt to get warm through slipping of the belt.

65. Brushes Improperly Set.—Brushes may be out of their proper position in either of two ways: they may be the right distance apart but too far one way or the other as a whole; this can, of course, be remedied by shifting the rocker-arm back and forth until the neutral point is found. The brushes may, as a whole, be central on the commutator, but too far apart or too close together. Such a fault must be remedied by adjusting the individual holders. On two-pole machines the two sets of brushes are placed diametrically opposite each other. On four-pole machines having two sets of brushes, the distance between the centers of the two sets should be just one-fourth of the circumference of the commutator. On four-pole machines having four brushes, they should set on the quarter; the best and quickest way to get this set in position is to place two sets at diametrically opposite points, the two remaining sets then go half way between them. In any case, for all commutator machines that are not special, the distance between the centers of adjacent sets of brushes should be the total number of commutator bars divided by the number of poles.

66. Commutator Rough or Eccentric.—A commutator will become rough either as a result of abuse or as a result of bad selection of the copper and mica of which it is made. If the mica is too thick or too hard, it will not wear as fast as the copper and will stand out in ridges. If too soft, it will eat out and make a furrow between bars that will catch carbon or copper dust and create local short circuits. An eccentric commutator acts like a bent shaft and may be the result of faulty workmanship or the result of a hard blow. In either case it must be turned true, but before doing it be certain that the commutator is at fault and not the shaft.

67. High or Low Bar.—A high or low commutator bar causes a clicking sound to be emitted whenever it passes under the brush. A high bar can often be removed with a file, but a low bar requires that the whole commutator be turned off.

68. Brushes Making Poor Contact.—Poor brush contact may be due to any one of several causes. The brush may be stuck in the holder; the temper may be out of the tension spring; the brush hammer may rest on the side of the holder and not on the brush; the brush may not fit the surface of the commutator; the holder may have shifted to the wrong angle. New brushes should be sandpapered to fit the commutator; the hammer should rest over the slot that guides the brush, so that when the brush wears it will follow it down. Tension springs should be paralleled by a conductor attached to the brush, so that the current will not flow through the springs and take the temper out of them.

69. Dirty Brushes or Commutator.—Carbon brushes are liable to give out paraffin when hot, which, getting on the commutator, insulates it in spots. The paraffin is also liable to mix with carbon dust and coat the brush with a non-conducting, sticky substance. A copper brush is apt to get clogged with oil, dust, and threads of waste (waste should never be used on a commutator). Brushes should be kept trimmed and cleaned. Dirty commutators, as a rule, are the result of using too soft a brush.

70. Too High a Speed.—A machine is apt to spark if its speed is too high, because it interferes with the commutation.

71. Sprung Armature Shaft.—A sprung armature shaft causes the commutator to wabble, giving very much the same symptoms as an eccentric commutator, and great care must be taken not to confuse a sprung shaft with an eccentric commutator.

72. Low Bearings.—On some types of machine, excessive wear in the bearings throws the armature far enough out of center to distort the field and cause sparking. Modern machines intended to stand fluctuating loads are so designed that there is no danger on this account.

73. Worn Commutator.—When a commutator wears down below a certain point, even if otherwise in good

condition, it seems inclined to spark in spite of everything that can be done. It may be because the brushes then span more bars, because the bars become thinner as they wear away, or it may be because an error in the angle of the holder increases with the distance from the commutator. The effect is most noticeable on some street-railway motors where it is almost impossible to run together two motors whose commutators differ greatly in size. The brush holder should be kept as near the commutator as possible, as it not only enables the bars to be counted off more accurately, but it holds the brushes at a short leverage and prevents chattering.

74. Short-Circuited or Reversed Armature Coil. Either of these faults will cause a local current to flow, with the result that either a dynamo or a motor will require an unusual amount of power to run it even when unloaded. The reversed coil can be located by sending current through the coils one at a time and holding a compass over them. A short-circuited coil can be detected by holding a piece of iron up to the head of the armature while it is running; there will be a decided pulsation of the iron once each revolution. Also, a motor will run with a jerky motion especially noticeable at low speeds, and the voltmeter connected to a dynamo will fluctuate. Such a fault may be due to a cross in the coil itself or contact between two commutator bars. In either case, unless the cross is removed, the coil will burn out.

75. High-Resistance Brush.—Up to a certain point, high resistance in a carbon brush is a good feature, and that is why they are used. But it is possible to get the resistance so high that the brush will spark on account of its inability to carry the current at the contact surface. Such a brush will get very hot and will be slowly chewed off at the wearing end.

76. Vibration.—A shaky foundation will cause the whole machine to vibrate and will cause it to spark steadily, which fault can be remedied only by placing the machine upon a firmer foundation.

77. Belt Slipping.—A slipping belt will cause intermittent sparking because it subjects the machine to unusual variations in speed.

78. Open-Circuited Armature.—By an open-circuited armature is meant a break in one of the armature wires or its connections. Excessive current may burn off one of the wires or a bruise of some kind may nick a wire so that the normal load or less burns it off. A commutator may become loose and break off one or more leads. In any case there are two very characteristic symptoms of an open-circuited armature: a ball of fire runs around the commutator and the mica is eaten from between the bars to which the faulty coil is connected, the bars themselves become dark, pitted, and burned on the edges. Sometimes, on account of abuse, the armature throws solder and all the commutator connections become impaired. In such a case there are no actual open circuits, but there are a series of poor contacts that result in making the commutator rough and black, pitting the bars and eating the mica.

79. Weak Field.—A weak field may be due to a loose joint in the iron circuit, to a metallic short circuit in the field coils, to opposition of the field coils, or to the fact that heat has carbonized the insulation on the field coils so that the current short-circuits through it. Any of these influences decrease the number of lines of force that cross the armature, with the result that the starting power of the motor is decreased, and the speed and current are increased. On a dynamo, the E. M. F. and the ability to pick up are decreased.

80. Grounds.—On a metallic-return circuit, a single ground has no effect, but two grounds can so take place that the whole or any part of the field or armature may be cut out; such a pair of grounds is nothing more nor less than a short circuit and it falls under that head. On a ground-return circuit, a ground anywhere except in the armature has, as a rule, but one indication: there is a flash and the armature burns out.

ALTERNATING-CURRENT MACHINERY.

ALTERNATORS.

81. The points given in regard to installing and handling the parts of direct-current machines hold good in regard to alternators. On account of the higher voltages used and the peculiar nature of the alternating current, abrasion of insulation through careless handling is apt to cause more serious trouble than on the lower voltage direct-current devices.

Alternating-current dynamos may be self-exciting or separately excited. As a rule, on account of the flexibility of control they are separately excited from a direct-current machine either coupled to the shaft of the alternator itself or run from an independent agent. In some cases the separate excitation is assisted by a current from the machine itself, this current being rectified by means of a commutator fixed on the shaft. The main and important advantage of separate excitation is that attendants are not called on to handle devices carrying the high voltage of the alternator in their ordinary duties of regulation.

Fluctuations of the voltage may be caused by slipping of the belt of the alternator or that of the exciter. This is one point in favor of directly connected machines with the exciter on the same shaft. All chance of fluctuation due to belt slipping on the exciter is then eliminated. As with any other separately excited machines, the direction of rotation of an alternator is immaterial as far as generation is concerned, but due regard must be had for the brushes on the rings and commutator if the machine has a rectifier.

Where there are two or more alternators to be run in multiple that are not excited from dynamos coupled to their own shafts, it is a good idea to excite them all from the same dynamo. The exciting plant should consist of at least two like units so wired that either can be used, which should be used alternately to insure that both are kept dried out and in good working order. Each alternator field can then be

controlled by means of a resistance box in series with it. Alternator armatures are constructed along such simple and substantial lines that they give few of the petty troubles incidental to direct-current practice. Most of the trouble lies in the exciter and its circuit, so that the service of the alternator as a whole is influenced by all the troubles likely to arise in any direct-current circuit. If the exciter is out of order, so is the alternator; if the exciter breaks down, so does the alternator, unless provision is made for quickly throwing in a second exciter. If the exciter belt slips or its brushes spark or either the iron or copper part of the field circuit is impaired, the voltage of the alternator goes down.

Where the machine is alone on a circuit, it is started in the same way as any other isolated dynamo; it is brought up to speed, the field excited by closing the field circuit, and the voltage regulated with the field rheostat. To shut down, the same operations are gone through in the reverse order. Alternating-current machines have a great deal of self-induction; some of them have so much that even on a short circuit the current is not large enough to burn them out. On account of this great self-induction, a dynamo should not be unnecessarily subjected to violent variations in load. For example, if the circuit of an alternator is suddenly opened under full load, the high induced E. M. F. is liable to puncture the insulation and cause a breakdown.

82. Alternators in Parallel.—When alternators are operated in parallel with one another, they must all run at such speeds that their currents will be in step with one another; that is, the several currents must vary in unison with one another, all the currents coming to their maximum values at the same instant. When this condition exists, the machines are said to be *in synchronism;* and before one alternator is thrown in parallel with another, the attendant must make sure that the machine to be thrown in is in synchronism with those already in operation. This is usually indicated by synchronizing lamps or by a synchronizing voltmeter. Some synchronizing lamps are connected so

that they go out when the machines are in step, while others are connected so that they light up. The attendant should always be sure as to just which way they are connected before he attempts to throw the machines in parallel. After the alternators are running together smoothly, their loads are adjusted by varying the power supplied to them.

ALTERNATING-CURRENT MOTORS.

83. Alternating-current motors call for the same general care as dynamos. Like all other dynamo machinery, they must be kept clean. Alternating-current machinery is generally operated at high pressure, and cleanliness is, therefore, absolutely necessary. In stations, it will pay to pipe compressed air to the machines and use a strong blast for blowing the dust and dirt out of the windings. Most of the motors in common use are of the synchronous, or induction, type.

84. Synchronous Motors.—These are the same in general construction as alternators. They are not intended to start up under load, but will run up to speed when connected to the line. In doing so they take a fairly large current, and in some cases, therefore, are brought up to synchronism by some outside source of power—as, for example, a small induction motor—before being connected to the line. Synchronous motors are separately excited and, in fact, are almost the same throughout as a separately excited alternator.

85. Induction Motors.—These motors are used for most work where the motor must frequently be started or stopped or where a good starting effort is required. In fact they are used for about the same kind of work as ordinary direct-current motors. There is nothing about them that requires any special care, that has not already been mentioned, after they are once installed. As a matter of fact, as they are inherently self-starting and have no commutator

to give trouble, they require fewer precautions and less judgment on the part of the operator than direct-current machines. At starting there is a tendency to permit an excessive flow of current; this not only strains the machine electrically, but on account of the great armature reaction, which weakens the field, the starting power is also decreased. The starting current is, therefore, limited by means of resistance. This resistance takes either the form of a stationary rheostat placed in the circuit of the armature through collector rings, or it is in the form of a resistance placed within the body of the armature and operated either by means of a lever operating a switch concentric with the shaft or automatically by centrifugal force.

The direction of rotation of a two-phase motor can be reversed by reversing the leads of either phase; that of a three-phase motor by reversing any one of the phases, thereby reversing the magnetic rotation of the field.

86. Many of the smaller sizes of induction motors are started by simply throwing in the main switch, but with the larger sizes, this gives too great a rush of current. When a starting resistance is used, it should be cut out rather slowly in order to give the machine time to gain speed. On the other hand, the starting resistance should not be left in too long, or there will be danger of overheating the motor. Never use a starting resistance for the purpose of regulating the speed. This applies to all motors, direct or alternating. Starting resistances are designed to carry current for a short time only, and if current is allowed to flow through them continuously they will be burned out.

87. Another method of starting induction motors that is used considerably is by means of what is called a **starting compensator.** This is a device inserted between the motor field and the line, and serves to cut down the voltage applied to the motor at starting, thus preventing a rush of current.

Fig. 23 shows the connections for one of these starting compensators. *A* is a double-throw switch, *B*, *B*, *B* the

line wires, and C the motor. In this figure the arrangement is shown for a three-phase motor. E, E, E are the coils wound on a laminated iron core similar to a transformer core. For a two-phase starter only two coils are necessary. These coils are provided with a number of taps, so that the compensator may be adjusted for different starting requirements. The switch is shown in the starting position, and by following out the connections it will be seen that one section of the coils is in series between the line and the motor field. One circuit, for instance, may be traced from m to s through m–n–o–p–r–s, when the switches are in the

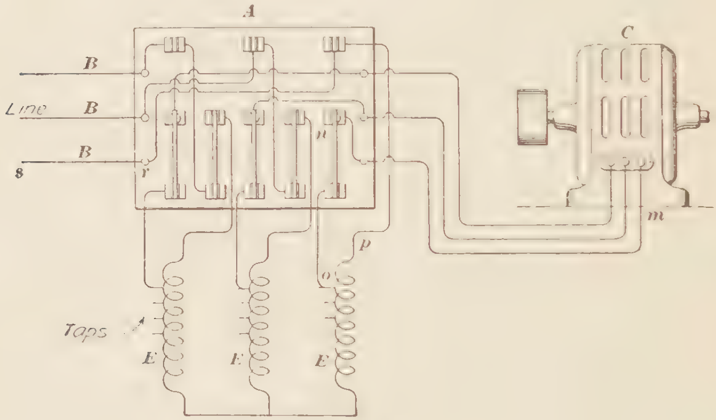


FIG. 23.

starting position. The E. M. F. developed in that portion of the coil between p and the adjustable contact o opposes, and hence decreases, the line voltage and allows the motor to start up gradually. After the motor is under headway, the switch is thrown up to the running position and one circuit may be traced through m–n–r–s. This cuts out the coils and connects the motor directly to the line. The operation of starting usually requires about 15 seconds for motors of moderate sizes. Always be sure that the starting device, no matter what kind it may be, is in circuit with the motor before throwing the main switch.

ROTARY TRANSFORMERS.

88. Rotary transformers, or converters, are used either to change alternating current to direct current or direct current to alternating. In most cases they are used to change alternating current to direct current, and when used to change from direct to alternating, they are often called **inverted rotaries.**

Rotary transformers combine the features of both direct-current machines and alternators, but on account of their peculiar nature a number of special points come up in connection with them that are not to be found with ordinary direct-current or alternating-current machines. The construction of the machine itself is very similar to that of a direct-current dynamo. The armature is provided with a winding in the same manner as the armature for a direct-current machine and this winding is connected to a commutator. The winding is also connected to collector rings, which serve to deliver alternating current to the machine. For example, when the rotary is used for changing alternating current to direct current, the alternating current is led into the armature winding by means of the collecting rings and is commuted, or changed, to a direct current, which is delivered to the lines attached to the brushes on the direct-current side. If direct current is supplied at the commutator, it flows through the windings and is changed to an alternating current, which is delivered from the collector rings. Rotary transformers when taking current from alternating-current lines run as synchronous motors, i. e., they run in step with the generator that drives them and their speed cannot change unless the speed of the generator changes. They may be run in parallel on either the direct-current or alternating-current sides.

89. Starting Rotary Transformers.—There are a number of different methods used for starting rotary transformers, and the one adopted will depend very largely on the conditions under which the machine is used. The following are some of the methods commonly used:

(*a*) *Starting from the Alternating-Current Side.*—When the machine is to be started from the alternating-current side, the fields are left unexcited and the armature is thrown into connection with the line through a starting resistance The machine then starts and runs up to synchronism, but in so doing takes quite a large current from the line. The machine starts as an induction motor by virtue of the currents induced in the pole faces by the currents in the armature. After the rotary has come up to speed, the field switch is closed. Another method is to have a small induction motor connected to the shaft of the main machine. This motor is started from the line and runs the large machine up to synchronism. The large machine is then thrown in, and it can thus be started without using an excessive line current. As soon as the rotary is running, it excites its own fields from the direct-current side.

(*b*) *Starting from the Direct-Current Side.*—When a rotary is already in operation in a station and it is desired to start up another, the simplest way is to start up the rotary as a shunt-wound direct-current motor by first seeing that its fields are separately excited and then inserting a resistance in the armature circuit and gradually cutting it out as the machine comes up to speed, like any other direct-current motor. In many stations where storage batteries are used, the rotaries are started by using direct current from the batteries, because they furnish a source of direct current that is always available whether other rotaries are running or not. Another very good method for supplying direct current for starting or exciting purposes is to equip a station with a small direct-current dynamo directly connected to an induction motor. When starting a rotary as a direct-current shunt-wound motor, always be sure that the field is excited before connecting the armature, also see that under no circumstances is the field circuit broken while the machine is running as a direct-current motor. If the above happens, the machine will race, and cases are on record where rotary converters have been almost completely

wrecked from this cause. Of course, where the machine is run from the alternating-current end, it runs in synchronism and the breaking of the field circuit will not result in racing. On the whole, however, starting with direct current is the preferable method.

(*c*) *Starting from the Alternator.*—This method of starting rotaries can only be used in comparatively few cases. It consists in connecting the rotary to the line and then starting the alternator in the distant station from which the rotary is operated. As the alternator comes up to speed, so does the rotary. This is a good method where it can be used, and especially where the rotaries are of large size.

(*d*) Another common method of starting is to have a small induction motor attached to an extension of the shaft of the rotary. This motor will start up readily when supplied with alternating current, and after it has brought the rotary up to speed it is cut out.

90. Hunting of Rotary Converters. — Sometimes rotary converters give a great deal of trouble due to what is known as *hunting*. The converter does not run uniformly, but develops a periodic variation in speed that causes wide fluctuations in the direct-current voltage. Excessive sparking is liable to result, and in some cases the effects have been almost as bad as a short circuit. This trouble has been particularly noticeable on converters made to operate at a fairly high frequency, say in the neighborhood of 60 cycles per second. Rotary converters are now generally operated on the lower frequencies, such as 40 or 25 cycles per second. When a machine hunts, the field shifts back and forth across the pole pieces, thus changing the position of the neutral field and giving rise to very bad sparking. The governor on the engine driving the alternator may be responsible for the hunting in the first place, or it may be caused by variations in the load, or by the influence of other machines on the same system. Its effects can be remedied to a considerable extent by putting heavy copper bridges

between the pole tips and by surrounding the pole face with a heavy copper ring. If the field then shifts back and forth, it will set up heavy currents in the ring, or bridges, and these currents will tend to oppose any shifting of the field.

TESTING FOR FAULTS.

91. Many of the defects that are liable to arise in connection with dynamos and motors are, of course, apparent from a mere inspection of the machine. Other defects, such as short-circuited or open-circuited field coils, short-circuited or open-circuited armature coils, etc., must be located by making tests. Many of these tests have already been referred to, and the following is intended to show how they are carried out. For tests of this kind Weston or similar instruments are most convenient if they have the proper range for the work in hand. For measuring resistances, the *drop-of-potential method* is generally most easily applied. This method consists in sending a known current through the resistance to be measured and noting the pressure between the terminals of the resistance; in other words, noting the pressure required to force the known current through the unknown resistance. The resistance may then be determined at once from Ohm's law, because $C = \frac{E}{R}$, or $R = \frac{E}{C}$. If the resistance to be measured is very low, as, for example, an armature coil, the voltmeter must be capable of reading low and a millivoltmeter (one reading to thousandths of a volt) will be best suited to the work. Of course, a good Wheatstone bridge may also be used for measuring resistances, but it is generally not as convenient to use around a station as the drop-of-potential method.

92. Testing for Open-Circuited Field Coils.—If a machine does not pick up, it may be due to the absence of residual magnetism. If any residual magnetism is present, a voltmeter connected across the brushes will give a small

deflection when the machine is run up to full speed, so that this point can easily be determined before a test is made for a broken field coil. Examination of the connections between the various coils will show if they are defective or loose; quite frequently the wire in the leads from the spools becomes broken at the point where the leads leave the spool, while the insulation remains intact, so that the break does not show. This may be detected by "wiggling" the leads.

If the break is inside the winding of one of the coils, it can only be detected by testing each coil separately to see if its circuit is complete. This may be done with a Wheatstone bridge or with a few cells of battery and a galvanometer. A low-reading Weston voltmeter makes a good galvanometer to use for this purpose.

If the current from another dynamo can be obtained, the faulty spool may be detected by connecting the terminals of the field circuit to the terminals of the circuit of the other machine; no current will flow through if the circuit is broken, but if a voltmeter is connected across each single field coil in succession, it will show *no deflection* if the coil is continuous, because both poles of the voltmeter will be connected to the *same* side of the dynamo circuit. If the coil has a break in it, one of its terminals will be connected to one side of the circuit and the other to the other side, so that a voltmeter connected between these terminals will show the full E. M. F. of that circuit. Consequently, when the voltmeter is connected across a spool and shows a considerable deflection, that spool has an open circuit which must be repaired before the dynamo can operate.

This method of testing is represented by the diagram, Fig. 24; *1*, *2*, *3*, and *4* represent the field coils of a four-pole dynamo, there being a break in coil *2* at *B*. The terminals *a* and *e* of the field winding are connected to the + and − terminals of a "live" circuit; that is, a circuit connected to a dynamo in operation. It will be seen that terminals *a* and *b* of coil *1* are both connected to the + side of the circuit, and as there is no current flowing through the field circuit, there is no difference of potential between *a* and *b*;

therefore, a voltmeter connected to *a* and *b*, as at *V*, will show no deflection. But terminal *c* of coil *2* is connected to the — side of the circuit; so a voltmeter connected to *b* and *c*, as at V_1, will show a deflection, and, in fact, will indicate the difference of potential between *a* and *e*.

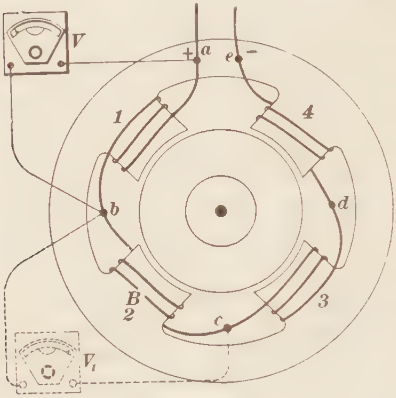


FIG. 24.

The above test may be roughly made with a bit of wire long enough to span from terminal to terminal of a coil. If one end of the wire is touched on *a*, for instance, and the other on *b*, it will not affect the circuit; but if it is touched on the terminals of the coil in which the break is located, the field circuit will be completed through the bit of wire, and a spark will occur when the wire is taken away. The wire should not be allowed to span more than one coil at a time, otherwise it may short-circuit so much of the field winding that too great a current will flow.

93. Short-Circuited Field Coil.—It is evident that if the windings of a field coil become short-circuited, either by wires coming in contact or by the insulation becoming carbonized, the defective coil will show a much lower resistance than it should. The drop of potential across the various field coils should be about the same for each coil, so that if one coil shows a much lower drop than the others, it indicates a short circuit of some kind.

94. Test for Grounds Between Winding and Frame. After the machine has thoroughly warmed up, it should be tested for "grounds," or connections between the winding and the frame or armature core. This may best be done with a good high-resistance voltmeter as follows: While

the machine is running, connect one terminal of the voltmeter to one terminal of the dynamo, and the other terminal of the voltmeter to the frame of the machine, as represented in Fig. 25, where T and T_1 are the terminals of the dynamo, and V and V_1 two positions of the voltmeter, connected as described above.

If in either position the voltmeter is deflected, it indicates that the field winding is grounded somewhere near the *other* terminal of the dynamo; that is, if the voltmeter at V shows a deflection, the machine is grounded near the

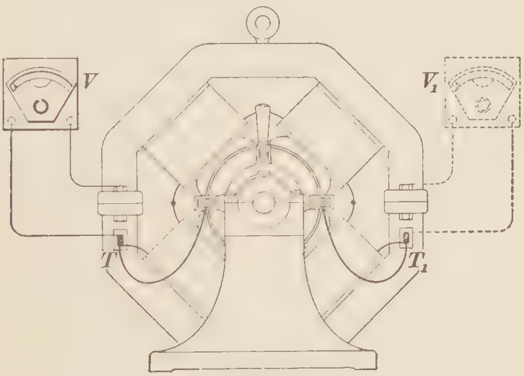


FIG. 25.

terminal T_1, and *vice versa*. If the needle shows a deflection in *both* positions, but seems to vibrate or tremble, the armature or commutator is probably grounded. If in either case the deflection does not amount to more than about $\frac{1}{20}$ the total E. M. F. of the machine, the ground is not serious, but if the deflection is much more than this, the windings should be examined separately, the ground located, and, if possible, removed.

95. To locate the ground, if thought to be in the field coils, each coil should be disconnected from its neighbor (with the machine shut down, of course) and "tested out" by connecting one terminal of another dynamo (or of a

"live" circuit) to the frame of the machine, care being taken to make a good contact with some bright surface, such as the end of the shaft or a bolt head, and the other to a terminal of the coil to be tested, through a voltmeter, as represented in Fig. 26.

Here C and C_1 represent the terminals of a "live" circuit, which should have a difference of potential between them about equal to the E. M. F. of the machine when it is in operation, but not greater than the capacity of the voltmeter will allow of measuring. T and T_1 represent the terminals of the dynamo, as before, and t and t_1, the terminals of the field coils, which have been disconnected from each other and from the dynamo terminals. One terminal C of the circuit is connected to the frame of the machine; the other terminal C_1 of the circuit is connected through the voltmeter V to the terminal t_1 of the field coil. If that coil is grounded, the voltmeter will show a deflection about equal to the E. M. F. of the circuit C C_1, but if the insulation is intact, it will show little or no deflection. The wire connecting the voltmeter with the terminal t_1 may be connected in succession to the terminal of the other coil, or coils, and to the commutator; any grounded coil of the field or armature winding will be shown by a considerable deflection of the voltmeter needle.

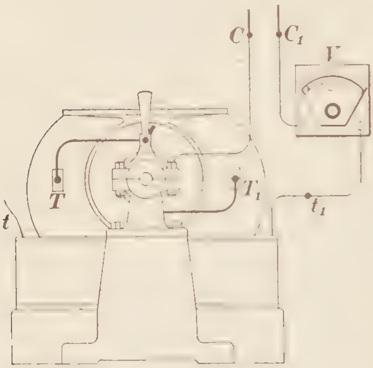


FIG. 26.

96. If the machine tests out clear of grounds, it should be shut down after the proper length of time and the various parts of the machine felt over to locate any excessive heating. If accurate results are wanted, thermometers should be used, placing the bulb on the various parts (armature, field coils, etc.) and covering it with a wad of waste

or rags. They should be looked at from time to time until it is seen that the mercury no longer rises, when the point to which it has risen should be noted. A thermometer hung on the wall of the room will give the temperature of the air, and the difference between the air temperature and that of the various parts of the machine should not exceed the prescribed limit.

97. Test for Defects in Armature (Bar-to-Bar Test).—Faults in armatures may best be located by what is known as a **bar-to-bar test.** This consists briefly in sending a current through the armature (in at one side of the commutator and out at the opposite side) and measuring the drop between adjacent bars all around the commutator. If the armature has no faults, the drop from bar to bar should be the same for all the bars. The connections for this test are shown in Fig. 27. *E* is the line from which the current for testing is obtained and *L B* a lamp bank by means of which the current flowing through the armature may be adjusted. Connection is made with the commutator at two opposite points *A*, *B*. A contact piece, or crab, *C* is provided with two spring contacts that are spaced so as to rest on adjacent bars. These contacts are connected to a galvanometer, or

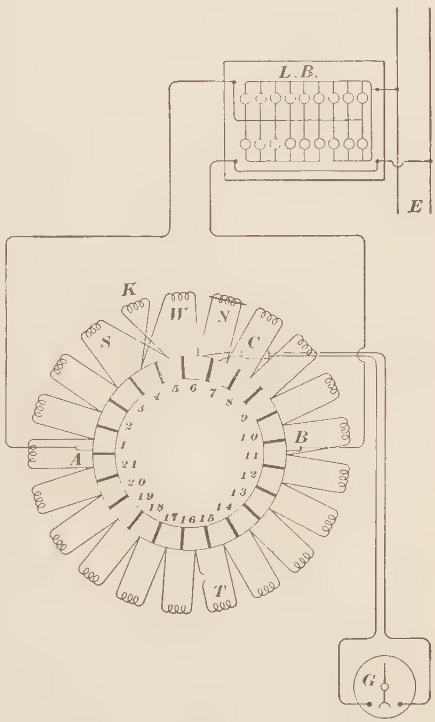


FIG. 27.

millivoltmeter, *G*. For the sake of illustrating the way in which the bar-to-bar test will indicate various kinds of faults, we will suppose that in coil *N* there is a short circuit, that the commutator leads of coils *S*, *K*, and *W* have been mixed, as shown, and that there is an open circuit in coil *T*. Current will flow through the top coils from *A* to *B*, but not through the bottom coils on account of the open circuit at *T*. Terminals *A*, *B* may be clamped permanently in place by means of a wooden clamp, or a strap such as shown in Fig. 28 may be used.

FIG. 28.

98. It is evident that the deflection of the galvanometer will depend on the difference of potential between the bars. If everything is all right, practically the same deflection will be obtained all around the commutator, no matter on what pair of bars *C* may rest. The test is carried out as follows: Adjust the lamp bank until the galvanometer, or voltmeter, gives a good readable deflection when *C* is in contact with what are supposed to be good coils. The amount of current required in the main circuit will depend on the resistance of the armature under test. If the armature is of high resistance, a comparatively small current will give sufficient drop between the bars; if of low resistance, a large current will be necessary. The operator runs over several bars and gets what is called the standard deflection and then compares all the other deflections with this. In case he should start on the damaged part, he will find when he comes to the good coils a difference in deflection.

If the contact rests on bars *3*, *4*, it is easily seen that a deflection much larger (about double) than the standard will

be obtained, because two coils are connected between *3* and *4* in place of only one. When on *4* and *5*, the deflection of the voltmeter, or galvanometer, would reverse, because the leads from *K*, *S*, and *W* are crossed. The deflection would not be greater than the standard, because only one coil is connected between *4* and *5*. Between *5* and *6* a large deflection will be obtained for the same reason that a large one was obtained between *3* and *4*. Between *6* and *7* little or no deflection will be obtained, because coil *7* is here represented as being short-circuited and, hence, there will be little or no drop through it. As *C* is moved around on the lower side, no deflection will be obtained until bars *15* and *16* are bridged. There will then be a violent throw of the needle, because the voltmeter will be connected to *A* and *B* through the intervening coils. When *C* moves on to *16* and *17*, there will again be no deflection, thus locating the break in coil *T*. As a temporary remedy for this, bars *15* and *16* may be connected together by a "jumper" or piece of short wire.

99. If any of the coils have poor or loose connections with the commutator bars, the effect will be the same as if the coil had a higher resistance than it should and, hence, the galvanometer deflection will be above the normal. In practice, after one has become used to this test, faults may be located easily and rapidly. It is best to have two persons, one to move *C* and the other to watch the deflections of *G*.

100. Locating Short-Circuited Armature Coils. Where there are a large number of armatures to be tested, as, for example, in street-railway repair shops, an arrangement similar to that shown in Fig. 29 is very convenient for locating short-circuited coils. *A* is a laminated iron core with the polar faces *b*, *b* (in this case arranged for four-pole armatures). This core is wound with a coil *c* that is connected to a source of alternating current. The core is built up to a length *d*, about the same as the length of the armature core. The core *A* is lowered on to the armature, and when an alternating current is sent through *c* an alternating magnetization is set up through the armature coils.

This induces an E. M. F. in each coil; and if any short circuits exist, such heavy local currents are set up that the short-circuited coils soon become hot or burn out, thus indicating their location. If an armature with a short-circuited coil is revolved in its own excited field, the faulty coil promptly burns out, so that this constitutes another

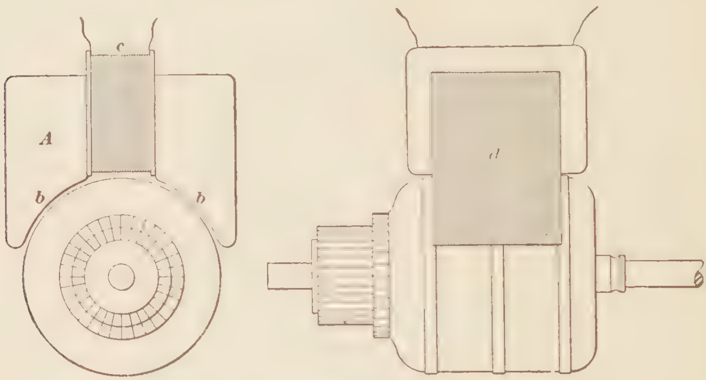


FIG. 29.

method of testing for such faults. To cut out a short-circuited coil, temporarily disconnect its ends from the commutator and bend back the ends out of the way and tape them so that they cannot touch each other and put a short piece of wire, or "jumper," in place of the coil so disconnected. It is always best, however, to replace the defective coil, because if the turns are short-circuited on each other, the coil may persist in heating and thus damage other coils.

RHEOSTATS FOR TESTING PURPOSES.

101. When tests are being made on machines, some form of adjustable resistance is necessary in order to get a variable load. If the current to be handled is not large, a lamp bank is very convenient, since the resistance may readily be changed by cutting lamps in or out. Another very convenient form of resistance for testing purposes may

be made by slitting a sheet of ordinary roofing tin into strips, as indicated in Fig. 30, and attaching this sheet to a wooden frame. The strips should be from $\frac{1}{2}$ inch to $\frac{3}{4}$ inch wide, and the sheet should be slit to within $\frac{1}{2}$ inch on alternate edges, so that when it is stretched out and held in position, it will form one continuous conductor. The resistance may be adjusted by a sliding crosspiece *S*, which short-circuits any required amount of resistance. Frames of this kind can be made of different current capacities depending on the width of strip used.

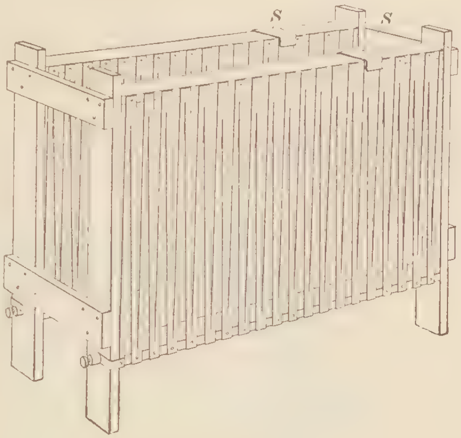


FIG. 30.

102. Water Rheostat.—When heavy currents are to be handled, a **water rheostat** is convenient. This usually consists of a wooden tank filled with salt water, in which are hung two iron (or other metal) plates that are attached to the terminals of the dynamo. The circuit is thus completed through the water between the plates, and, by varying the distance between the plates, the resistance of the external circuit can be adjusted between wide limits.

An old oil barrel makes a good tank if the dynamo to be tested has an output of not more than about 15 kilowatts. If a greater amount of energy must be disposed of, the surface and the amount of the water must be greater than a barrel will afford, and a tank should be made for the purpose, especially if several machines are to be tested. Fig. 31 illustrates a form of water rheostat, in which *T* is the wooden tank, which should be about 7 feet long and about $2\frac{1}{2}$ feet square, inside measurements, made of $1\frac{1}{2}$-inch or 2-inch

pine plank, with tongued-and-grooved joints that should be leaded to make them tight, the whole being held together by cross bolts, as represented in the figure.

Two iron rods *R*, *R* are placed across the top of the tank, to which are attached the terminals of the dynamo circuit, as represented at *W*, *W*. From these rods two iron plates *P*, *P* are hung, which should have about 3½ or 4 square feet of surface (on one side) below the water level. These plates may be made of a couple of pieces of old boiler plate

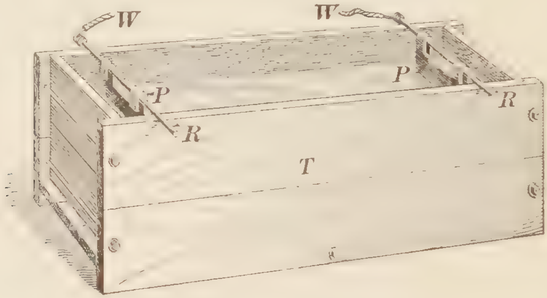


FIG. 31.

or heavy (¼-inch or thicker) sheet iron, cut with two projecting lugs on the top, which are bent into hooks by which the plates are hung from the rods *R*, *R*. Cast iron will do equally well; two old ash-pit doors, for example, will make very good plates, the rods being passed through the holes for the hinge pins. When ready for use, the tank should be filled with water, and from 5 to 20 pounds of rock salt or washing soda added to reduce the resistance to the required figure, as water alone will give altogether too high a resistance.

DYNAMO-ELECTRIC MACHINERY.

CONSTANT-CURRENT DYNAMOS.

1. If an ordinary series-wound dynamo is connected to an external circuit whose resistance is variable, both the current and the E. M. F. will vary. For example, if the external resistance is increased, the current will be diminished; as the machine is series-wound, this weakens the field, which lowers the E. M. F. and still further decreases the current. If the external resistance is decreased, the current and E. M. F. will each be increased.

In order to obtain a constant current in a circuit of variable resistance, it is necessary, then, to vary the E. M. F. of the machine as the resistance changes, and in the same proportion. There are many different devices for accomplishing this, as will be described.

In general, the field magnets of constant-current dynamos may be bipolar or multipolar, with salient or consequent poles, according to the ideas of the designer. They are usually series-wound. The armature windings, however, may be divided into two classes, *closed coil* and *open coil.*

CLOSED-COIL ARMATURES.

2. Closed-coil armatures have already been described in connection with constant-potential dynamos. Ring armatures are generally used in constant-current dynamos, on account of their good ventilation, and from the ease with

which any damaged coil may be repaired, since a coil can be replaced without disturbing others, which is not the case in the usual form of drum windings, where the coils overlap.

3. The methods used to regulate the E. M. F. of closed-coil armatures are as follows: (1) Varying the speed; (2) varying the strength of the field; and (3) shifting the brushes.

The first method is seldom used, though in special cases it is very convenient. The principle of this method is that with a simple series-wound dynamo, if the external resistance is increased, decreasing the current and E. M. F., the speed may be increased until the E. M. F. rises to a point where it will force the normal current through the external circuit; if this adjustment of the speed is made as rapidly as the external resistance changes, the current will be maintained at a constant value.

4. The second method has already been described in connection with series-wound dynamos. It is evident that this same principle may be applied to constant-current machines, so as to properly vary the E. M. F. The range of this method of regulation is quite limited, because the strength of the field cannot be economically forced beyond the point where the iron begins to be saturated, and if it is much reduced, the armature reaction (which is constant, since the current is constant) will cause the neutral point to considerably alter its position.

5. The third method is almost universally used in this type of machines. It has already been pointed out that the greatest difference of potential in a (bipolar) closed-coil armature exists between the two opposite coils that are in the neutral spaces; so, to get this maximum difference of potential between the brushes, they are placed on the opposite commutator segments that are connected to these two coils. Now, if the brushes are shifted from this position, although the E. M. F. generated in the armature is not altered, the *difference of potential between the*

brushes is reduced; for, although the circuit through the armature winding is still divided into two parts connected in parallel between the brushes, the separate E. M. F.'s of all the coils in each of the two parts are not all in the same direction.

6. If there were no armature reaction, shifting the brushes to a point half way around the commutator from the neutral space would reduce the difference of potential between them to zero; and in positions between these two, the difference of potential would be proportional to the amount of shift. Since the coils short-circuited by the brushes would be moving in strong magnetic fields, there would also be violent sparking.

There is, however, a very considerable armature reaction in dynamos of this type, which is so proportioned with respect to the strength of the field that it has two effects. One is to shift the neutral point so that the difference of potential between the brushes is not quite proportional to the amount of shift; but this is of little importance compared to the second effect, which is that the tendency of the current in the armature winding to form consequent poles at the points where the current enters or leaves the winding through the leads to the commutator actually *forces the lines of force of the field from the armature at these points*, leaving only a weak field to influence the short-circuited coil. By proper proportioning of the armature winding, this results in little or no sparking at the brushes, especially as the amount of current in a constant-current machine seldom exceeds 10 amperes, which allows the use of such a narrow brush that the time during which a coil is short-circuited is so short that the current in the coil does not have time to become large enough to cause serious sparking.

The brushes may be shifted by hand to get the desired regulation, but as this would require constant attention, it is usual to shift the brushes automatically by devices on or near the dynamos. These devices are usually controlled about as follows: Electromagnets are connected in the

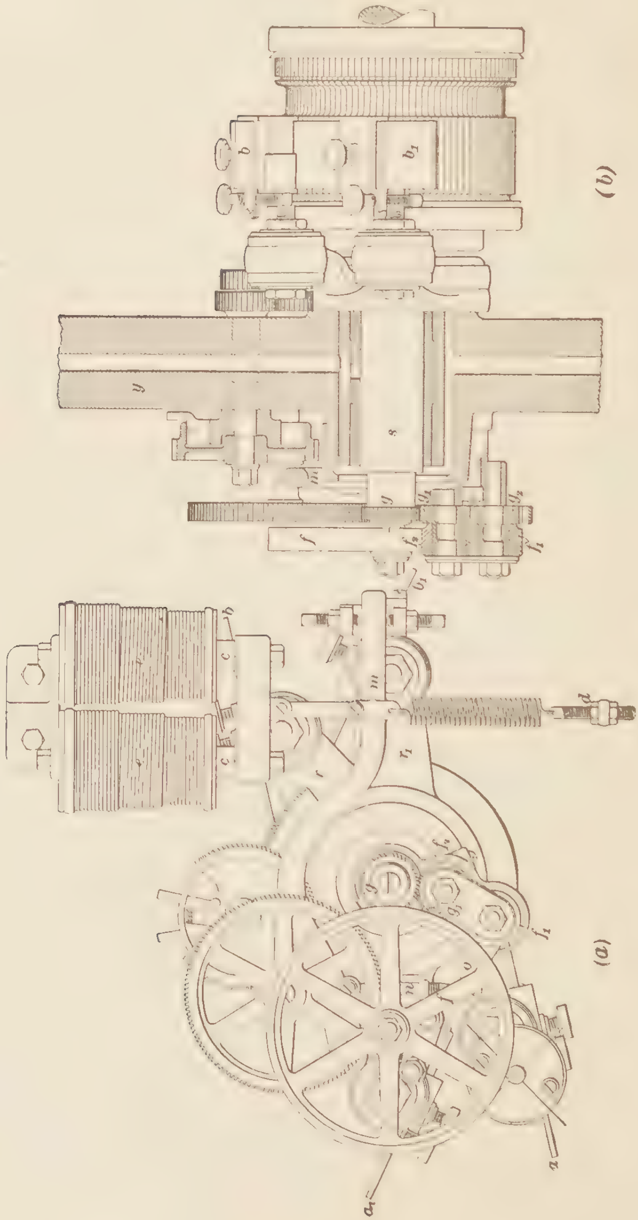


Fig. 1.

main circuit and are so adjusted that when any change in the external resistance causes the current to increase or decrease from normal, the corresponding movement of the magnet keeper mechanically connects the rocker-arm of the dynamo to some sort of driving mechanism, so that the brushes are properly shifted. When they reach such a point that the current is again at its normal value, the electromagnet (usually called the *controlling magnet*) disconnects the rocker-arm from the driving mechanism, and the motion of the brushes ceases until some change in the external circuit calls for a new adjustment.

The mechanical parts of the various brush-shifting devices are quite different in the different makes of constant-current machines. In the following description of the principal features of some of the best known types of closed-coil, constant-current machines, the types of regulating devices used will be taken up more in detail.

PRINCIPAL CLOSED-COIL CONSTANT-CURRENT DYNAMOS.

7. Wood Dynamos.—These machines have bipolar, consequent-pole, series-wound field magnets and ring-wound armatures of quite large diameter.

A regulator that has been used largely on these dynamos is shown in Fig. 1 (*a*) and (*b*). To reduce the sparking to a minimum, it has been found desirable to use two positive brushes a, a_1, shown only in (*a*), located a little distance apart on the commutator, and two negative brushes b, b_1, located opposite the positive brushes. The brushes are mounted on opposite ends of the rocker-arms r and r_1, so that simply shifting these two effects the shifting of the four brushes. The angle between the rocker-arms r and r_1 of each pair of brushes is variable, preserving a distance between the bearing ends of the brushes equal to about three commutator segments at light loads (low E. M. F.), and about double this at heavy loads (high E. M. F.). This variation in distance is accomplished by shifting the *back* brushes a_1

and b_1 of each pair a little faster than the front brushes a and b are shifted, so that the back brush gradually overtakes the front one, lessening the distance between them, in shifting from the heavy-load to the light-load position.

The electromagnet e is connected in series with the armature, field, and external circuit, and furnishes the power for regulating the current. The cores c, c of this electromagnet are free to move into or out of the coils, the attraction of the magnet being balanced by a tension spring provided with an adjustment at d. The lever arm m is raised by the electromagnet when the current increases and is lowered when the current weakens. A small gear g on the end of the shaft continuously drives two friction rollers f_1, f_2 in opposite directions by means of the gears g_1, g_2. The movement of the lever arm m presses the friction wheel f, by means of the intermediate links n, o, against one or other of the friction rollers, thereby turning the friction wheel in a forward or backward direction. This motion is then communicated by means of gearing to the rocker-arms, producing the relative movement already referred to. The two positive and the two negative brushes are connected by short, flexible cables, so that the intervening coils on the armature are short-circuited. As the distance between the brushes increases, a larger number of coils will be short-circuited; as these coils lie, however, in the neutral space, the effect of cutting them out is to neutralize their demagnetizing action, thereby increasing the E. M. F. of the dynamo. In order to facilitate adjustment, the brushes are set to a certain length, the amount of their projection from the holders being determined by means of a gauge. The regulator is fastened to one of the yokes y of the field. In the larger sizes of these machines, the friction rollers are driven by a light belt from a small pulley on the end of the armature shaft, but otherwise operate in the same manner as that described.

In some of the latest type of Wood machines, the friction wheel f and the two friction rollers f_1, f_2 are replaced by a small, double friction clutch, driven by a belt from the

main shaft. In other respects, however, the construction and principle of operation are the same as that described above.

8. Standard Dynamos.—These machines have bipolar, consequent-pole, series-wound field magnets. The armature is of the ring type, and differs from that of the Wood machine only in the details of its construction. A single pair of brushes is used, which is shifted to vary the E. M. F. and to keep the current constant by a mechanism situated on the base of the machine. This mechanism is driven by a light belt from a small pulley fastened to the end of the armature shaft.

9. Western Electric Dynamos.—In the smaller sizes these machines have bipolar, consequent-pole, series-wound field magnets, with drum-wound armatures; in the larger sizes the field magnets are multipolar, with salient poles, and ring-wound armatures are used.

The machines are regulated to give a constant current by shifting the brushes, as in those previously described; the mechanism for shifting the brushes is driven by a belt from the end of the armature shaft and controlled by a separate controlling magnet, as in the Wood dynamo. The controlling magnet throws into or out of gear or reverses a friction-clutch arrangement, which shifts the brushes forwards or backwards as the load is increased or diminished.

The armature of the Western Electric arc dynamo is toothed, the coils being wound in slots, instead of on the surface. The slots are very carefully insulated because most of these machines generate a very high E. M. F. at full load. The commutator segments are mounted on a marble disk and are arranged so that they may be renewed when they are worn out. Another feature of the machine is that graphite brushes instead of copper are used.

10. Excelsior Dynamos.—These machines have bipolar, salient-pole, series-wound field magnets and use ring armatures. An iron arm projects from each pole piece,

forming the pole pieces for a small armature, which is operated as a motor to shift the brushes of the machine. This small armature is geared to the rocker-arm, and the controlling magnet is so arranged that if the current in the machine rises above the normal, a portion of the current is shunted through the armature of this small motor, which causes it to turn in such a direction that the brushes are moved from the neutral point, thus reducing the current.

At the same time, the motion of the rocker-arm operates a switch that cuts out some of the turns of the magnetizing coils, thus reducing the E. M. F. of the armature. It will be seen that this method of regulating the difference of potential between the brushes is a combination of the methods that have already been described.

If the current is decreased below the normal strength, the controlling magnet reverses the current in the armature of the small motor, so that it runs in the opposite direction and shifts the brushes towards the neutral point, at the same time cutting *in* some of the turns of the magnetizing coils, all of which brings the current back to its normal strength.

11. Ball Dynamos.—These machines are of a very peculiar construction. The magnetic circuit is represented in Fig. 2, from which it will be seen that two armatures are used, each with an independent commutator. The field magnet is arranged with only one pole piece for each armature, as represented; but as the lines of force must complete their circuit, they form irregular poles on the opposite side of the armature, the paths of the lines of force being represented by the dotted lines in the figure. The armatures are ring wound and each may be used separately or connected in series.

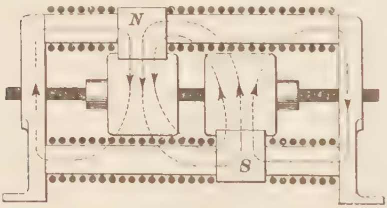


FIG. 2.

In the larger machines of this type, the regulation is obtained by automatically shifting the brushes, the field

magnets of the machine itself acting as the controlling magnet and also furnishing the necessary power. A circular opening is made in the magnetic yoke (on each end of the machine) of such size that the area of the magnetic circuit at that point is much reduced, which causes a leakage of the lines of force across the opening. Two iron segments are supported on a non-magnetic hub in this opening. Now, if these iron pieces were free to move, they would take such a position in the opening as to make up as much as possible for the reduction in the area of the magnetic circuit and allow the lines of force to pass directly through them. They are free to rotate about the hub to which they are attached, but are prevented from taking up their natural position by a counterweight, which deflects them more or less, according to the strength of the field of the machine.

The brush-holder studs are connected directly to this movable part of the magnetic yoke, so that when the strength of the field increases, due to an increase in the current above the normal strength, this movable part is pulled around against the opposition of its counterweight until the brushes are shifted to the point where the current again becomes of normal strength.

OPEN-COIL ARMATURES.

12. Open-coil windings consist of a comparatively small number of coils that are connected directly to the external circuit (through the commutator) when in the position where the E. M. F. generated in them is a maximum.

As the coils move from this position, they are connected in parallel with other coils, and are finally, when near the position where their E. M. F. is zero, disconnected entirely from the external circuit. These various connections are made by the brushes and the commutator, by means that will be explained in speaking of the principal makes of machines of this type. The changes in the connections of the coils and the small number of coils used make the

difference of potential between the brushes fluctuate, so that the current in the external circuit is *pulsating* in character. In speaking of it as a *constant* current, it is meant that the *average* current strength is constant.

PRINCIPAL OPEN-COIL CONSTANT-CURRENT DYNAMOS.

13. Brush Dynamos.—These machines use a disk-shaped ring-wound armature with projections on both sides of the ring, between which the coils are wound.

The magnetic circuit has four poles, but it is really a consequent-pole, bipolar field magnet, as will be seen from Fig. 3, which represents the field magnet as seen from the top.

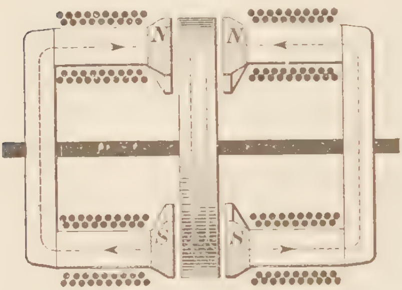


FIG. 3.

The armature winding of these machines consists really of a number of windings, each with a separate commutator. Each winding consists of four coils, arranged in two sets of two coils each. The two coils of each set are placed on opposite sides of the armature core, so that one coil is always in the same position relative to one pole piece that the other coil is to the other pole piece; this being the case, the E. M. F.'s generated in the coils are equal at all parts of their revolution, and they are permanently connected in series, so that they really act as one coil. The other set of coils belonging to the winding is placed on the core in the same manner, but at right angles to the first set, so that when the coils of one set are under the center of the pole pieces, that is, are in their most active position, the coils of the other set are in the neutral spaces, that is, in their least active position.

14. It will be seen that this arrangement of the two sets of coils corresponds to the arrangement of the two loops

of wire that has been previously described and illustrated. The ends of each of the two sets of coils are connected to two opposite segments of a commutator, as in the previous case, except that instead of each segment being a little less than one-fourth the circumference, so that the brushes leave one pair of segments at the same time that they begin to bear on the other pair, in the Brush commutator each segment covers a little more than one-third the circumference, the segments of one pair being placed alongside the segments of the other pair to allow for this extra length.

This is represented in Fig. 4, *a*, *a′* being the two segments connected to one set of coils, and *b*, *b′* being the two that are connected to the other set. It will be seen from this figure that each of the brushes *1*, *2* rests on one of the two opposite segments *b*, *b′*; but as the commutator revolves, each brush rests on one segment of *each* pair, *a′*, *b′* and *a*, *b*, where they overlap. Consequently, the coils connected to each pair of segments are connected in parallel with each other during a part of each half revolution.

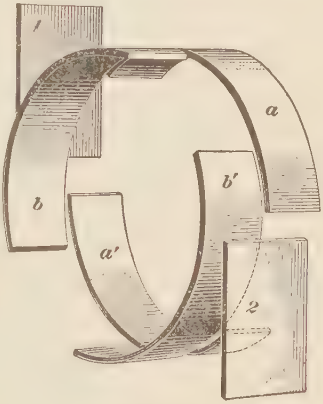


FIG. 4.

If this form of commutator with overlapping segments be connected to two simple loops, it will be seen that at the moment when the two loops of wire are thrown in parallel by each brush resting on two segments, the E. M. F. in the two loops is not the same, that of the loop which had just before alone been connected to the brushes being higher than that of the other. A little later, at the moment when one of the loops is disconnected from the circuit by each brush passing from two segments to a single segment, the coil that is disconnected has a less E. M. F. than the other.

If the loops had little self-induction, this would result in the greater E. M. F. of the one loop sending a current

around through the other loop against the E. M. F. generated in it, which current would not appear in the external circuit and would therefore represent so much wasted energy.

This *local current* would evidently be greatest when the difference between the E. M. F.'s of the two coils is greatest, that is, at the moment when the two loops are connected in parallel and at the moment one of the loops is disconnected from the brushes. Then, when the one loop is disconnected from the other, this local current would be suddenly broken, and this would result in sparking.

In the Brush machines, the self-induction of the coils is considerable, so that when two sets of coils are connected in parallel, the self-induction of the coil having the lower E. M. F. prevents this sudden rush of local current and takes up its share of the output of the machine gradually.

At the same time, the parallel connection of the sets of coils is not broken until the E. M. F. of the set that is disconnected is enough lower than that of the other set so that it is furnishing practically none of the current output; hence, there is little sparking when it is disconnected.

15. As stated, the Brush armature winding is made up of two or more separate windings, the action of each being as already described.

Fig. 5 represents a Brush armature with two separate windings. In this figure, the pole pieces are represented by the dotted lines as they face the sides of the armature, as shown in Fig. 3. The segments of the two separate commutators are, for convenience, represented as concentric, with the brushes resting on their edges; whereas, actually, they lie side by side, forming two separate commutators of the same diameter, each having four segments, and the brushes rest on their circumferences.

One winding consists of two pairs of coils A A' and B B' located at right angles to each other, the coils of each pair being connected in series, as represented.

This winding is connected to its commutator, coil A to

segment a, coil A' to segment a', coil B to segment b, and coil B' to segment b', as represented. Brushes *1* and *2* rest on this commutator, making contact on the line of maximum action $x\,y$ of the coils. It will be seen that this line is not from center to center of the pole pieces, but is moved ahead (in the direction of rotation, as indicated by the arrows) from this position by the armature reaction.

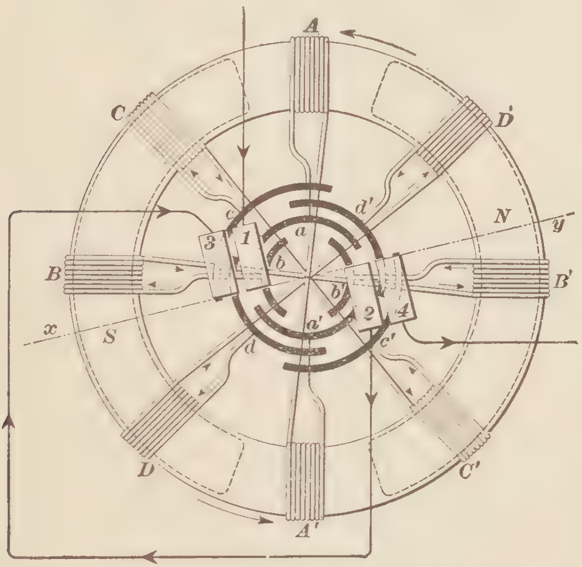


FIG. 5.

The second winding consists of two pairs of coils $C\,C'$ and $D\,D'$, located at right angles to each other and half way between the coils of the first winding. These coils are connected in series and to the segments of the second commutator, coil C to segment c, coil C' to segment c', coil D to segment d, and coil D' to segment d', as represented. Brushes *3* and *4* rest upon the segments of this commutator on the same line of maximum action of the coils.

Taking each winding separately, it will be seen that its two sets of coils pass through the following combinations: One set of coils only connected to the brushes; then the

two sets, connected in parallel and both connected to the brushes; then one set only; then both sets in parallel; and so on.

The maximum E. M. F. occurs when the single set of coils is connected and is directly in the line of maximum action; the minimum occurs one-eighth of a revolution ahead of this point, when both sets of coils are in parallel and are equally distant from the line of maximum action.

This being the case, it is evident that as the coils of one winding are half way between the coils of the other, *the maximum E. M. F. of one winding occurs at the same instant as does the minimum E. M. F. of the other.* On account of this, when the two windings are connected in series, the fluctuations of the current are much reduced.

This connection of the two windings is obtained by connecting, as shown in Fig. 5, the positive brush of one winding with the negative of the other, the external circuit being connected between the two remaining brushes.

In the large sizes of these machines, three and even four separate windings are used, each with its commutator, and all connected in series. In the larger multipolar machines, each winding consists of two sets of coils, each set containing four coils, one for each pole piece. The action is precisely the same as in the bipolar machine.

16. The regulation of the Brush machines is nearly automatic; that is, a machine will give *nearly* a constant current without any regulation whatever. This is due to the fact that the armature reaction increases so much with any increase in the current that the line of maximum action is shifted farther ahead, which changes the relations of the various coils at the time when they are connected with, or disconnected from, each other or the external circuit.

This regulation is, however, not close enough for commercial working; so in addition, a resistance is placed in shunt to the magnetizing coils, which is varied by a controlling magnet in the main circuit, thus making the regulation very exact.

This resistance consists of a series of blocks of carbon—a material that has the property of lessening its resistance if subjected to pressure. In this case the pressure is obtained by the pull of the controlling magnet on its keeper, which forms the end of a lever that presses upon the carbon blocks. If the current in the external circuit increases, due to a lessening of the external resistance, the controlling magnet pulls on its keeper with greater force, thus increasing the pressure on the carbons, decreasing their resistance, and weakening the strength of the field magnets, which reduces the E. M. F. of the armature coils until the current is again at its normal strength.

The shifting of the point of maximum action, due to the weakening of the field at light loads, causes a certain amount of sparking, which is remedied by slightly shifting the brushes. In the multipolar machines, this shifting is performed automatically by mechanism driven by a belt from a small pulley on the end of the armature shaft and controlled by the controlling magnet, as in the closed-coil dynamos described.

17. Westinghouse Dynamos.—These machines, which are comparatively new, use a multipolar field magnet having six salient poles. The armature coils are wound around eight projecting teeth on the armature core, there being, therefore, eight armature coils. With eight coils and six poles, it is evident that only two coils can be directly under any two pole pieces at the same instant. This armature winding, as in the Brush machine, is divided into two separate windings, each consisting of two pairs of opposite coils and each connected to a separate commutator. The combination of connections of the various sets of coils is similar to that of the Brush machine; that is, the set of coils in the position of least action is disconnected entirely from the circuit, those near the position of maximum action are connected in parallel and in series (by external connection of the brushes) with the set that is actually in the position of maximum action.

In this machine, a coil is in the position of least action when the projection on which it is wound is directly under a pole piece, for when in this position all the lines of force from the pole piece pass directly through the center of the coil, which therefore cuts none of the lines of force. As soon as the coil moves from this position, one side begins to cut the lines of force of the pole piece from which it is moving; then as it moves still farther, the *other* side of the coil begins to cut the lines of force of the pole piece *towards* which it is moving, so that when half way between the two, both sides of the coil are cutting lines of force equally and at the maximum rate, and this is, therefore, the position of *maximum* action.

18. A diagram showing the connections of the armature winding to the commutator of the Westinghouse machine is given in Fig. 6. As in Fig. 5, the two commutators are represented as concentric, though they are actually side by side on the shaft, and, as in the Brush machine, are situated on the end of the shaft outside one of the bearings, the leads to the commutator being brought out through a hole in the shaft, instead of being connected directly, as represented in the diagram.

The two pairs of coils A, A' and B, B' make up one winding and are connected to one commutator, as represented. The two opposite coils A, A' and B, B' are connected in series by connections across the back of the armature core (not shown in the diagram).

The other winding is made up of the two pairs of coils C and C' and D and D', the coils of each pair being connected in series, as before.

It will be seen that each commutator is made up of twelve segments separated by a considerable width of insulating material (indicated by the solid-black parts). These twelve segments are connected by cross-connecting wires, as shown in Fig. 6. The segments that are connected together are one-third a circumference apart, as, for example, segments d, d, d.

Instead of the segments overlapping as they do in the Brush machine, each brush is divided into two parts, which rest on the commutator at a distance apart equal to the length of one segment, as represented at *1 1′* or *2 2′*.

Applying the statement made in the last article to Fig. 6, it will be seen that coils *A* and *A′* are in the position of least action and are disconnected from the external circuit. The other set of coils of this winding, *B* and *B′*, is, however, in the position of maximum action and is connected to the

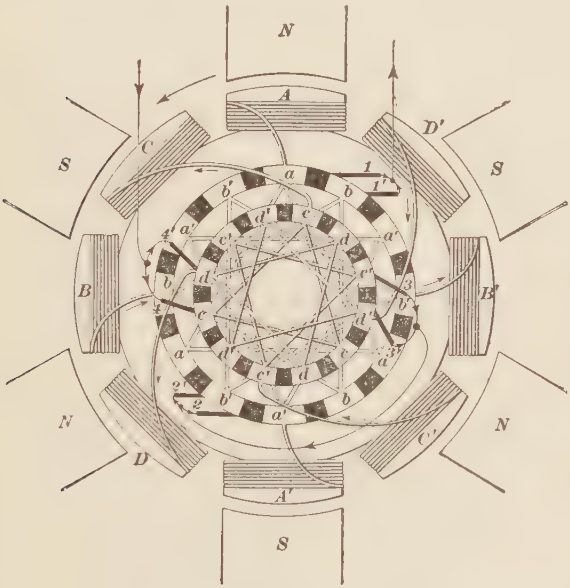


Fig. 6.

circuit through brushes *1* and *1′* and *2* and *2′*, which rest on segments *b*, *b′*, respectively. Of the second winding, each set of coils *C*, *C′* and *D*, *D′* is equally distant from the position of maximum action, and these two sets are therefore connected in parallel with each other through brushes *4*, *4′*, which rests on segments *c*, *d*, and brushes *3*, *3′*, which rest on segments *c′*, *d′*, and are connected in series with the

set of coils B, B' by the external connection between the two sets of brushes 2, $2'$ and 3, $3'$.

To follow out the changes in the connections of the coils, consider that the armature is moving in the direction indicated by the arrow. As coils B, B' move from their position of maximum action, brushes $1'$, $2'$ are disconnected from segments b, b', and as the armature moves, finally come into contact with segments a', a, thus throwing the two sets of coils A, A' and B, B' in parallel. At the same time, brushes 4 and 3 being disconnected by the insulating segment from segments c, c', coils D, D' only of the second winding are connected to the circuit through brush $4'$ and in series with the coils of the other winding (now connected in parallel) through brush $3'$ and its connection with brushes 2, $2'$, coils C, C' being entirely disconnected.

It will be seen that these successive combinations of coils are precisely the same as take place in the Brush machine, except that each combination takes place six times in each revolution, instead of twice, which is due to the multipolar field. The regulation of this machine is entirely automatic. The field magnets are separately excited, the current being furnished by a separate constant-potential dynamo, which gives a constant magnetizing force; but the strength and distribution of the resulting field are dependent on the armature reaction, which is so proportioned that any excess of current over the normal so reduces and distorts the field that the E. M. F. generated in a winding during the time that it is connected to the brushes is reduced until the current is again at its normal strength.

19. Thomson-Houston Dynamos. — These machines have bipolar, series-wound, salient-pole field magnets. The completed armature is nearly spherical in shape and the pole pieces are bored out accordingly, so that they almost entirely enclose the armature.

In the older machines, the armature is drum-wound, although the core is a ring, but in the newer machines, a ring winding is used; in either case, three separate coils, or

sets of coils, make up the winding. One end of each of these coils (or sets of coils) is connected to a commutator segment, all the other ends being joined together.

The commutator has three segments, each covering nearly one-third the circumference, the balance being made up by the air spaces that separate the segments.

Two positive and two negative brushes are used, those of each pair resting on the commutator at two points at a distance apart equal to one-half a commutator segment, that is, nearly one-sixth the circumference, when the machine is giving its greatest E. M. F.

20. A diagram of the connections, etc. of the drum-wound armature is shown in Fig. 7. *A A′*, *B B′*, and *C C′* are the three coils wound on the core one-third the circumference apart. One end of each of the coils is joined to a metal ring (not represented in the figure) on the back of the armature, which forms a common connection for the three.

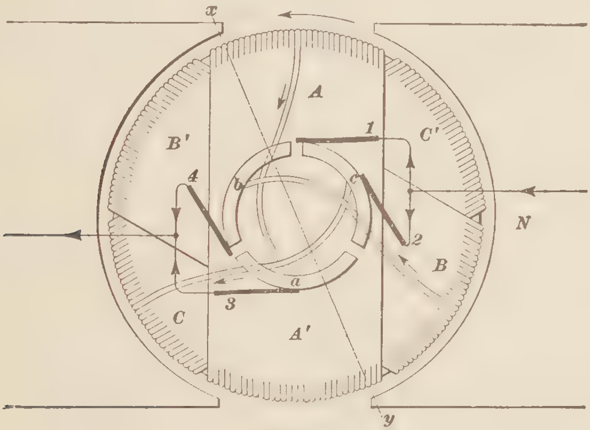


FIG. 7.

The other ends are joined to the commutator segments, that of *A A′* to segment *a*, that of *B B′* to segment *b*, and that of *C C′* to segment *c*, as represented; *1* and *2* are the negative, and *3* and *4* the positive, brushes. Brushes *2* and *4* are usually called the *primary* brushes and *1* and *3* the *secondary* brushes, to distinguish them.

From the diagram, Fig. 7, it will be seen that coil $A A'$, though half way between the pole pieces, is partly active, since the neutral line is shifted forwards by armature reaction, as indicated by the line $x y$. This coil $A A'$ is connected in parallel with coil $B B'$ by the two positive brushes, and the two are in series with coil $C C'$. If the armature be considered as moving in the direction indicated by the arrow, it will be seen that as coil $A A'$ gets to the position of least action, it is disconnected from the circuit by segment a passing from under brush *3*, leaving coil $B B'$ and coil $C C'$ in series. However, as the distance between brush *3* and brush *2* is only slightly greater than the span of one segment, coil $A A'$ is almost immediately connected in parallel with coil $C C'$, as segment a passes under brush *2*, making the following combination: Coil $B B'$ in series with coils $A A'$ and $C C'$ in parallel.

As the rotation of the armature continues, coil $C C'$ is disconnected from the negative brush *1* and connected to the positive brush *4*, being thus thrown in parallel with coil $B B'$, the two being then in series with coil $A A'$.

Completing the half revolution, coil $B B'$ is disconnected from the positive brush *3* and is joined in parallel with coil $A A'$ by the two negative brushes *1* and *2*, leaving coil $C C'$ connected to the positive brushes.

Further rotation of the armature repeats this series of connections; that is, during every half revolution, one of the coils ($A A'$ in the preceding paragraphs) is first in parallel with the coil *behind* it, then momentarily disconnected from the circuit, then connected in parallel with the coil *ahead* of it, then connected in series with the other two, which are then in parallel.

From the diagram, Fig. 7, it will be seen that when a coil is disconnected from one set of brushes, it is very nearly in the position of least action, and the coil with which it was just before connected in parallel has the higher E. M. F. of the two. As has been explained, the self-induction of the coil prevents the higher E. M. F. of the other sending a current through it in opposition to its own E. M. F. at the

time when they are connected in parallel; in fact, when the coil is disconnected from its mate, it is still supplying some of the current, so that there is a spark at the brushes.

21. The regulation of this machine is effected by varying the distance between the two brushes of each set, the primary brush being moved back and the secondary ahead. This movement of the brushes decreases the distance between the primary brush of one set and the secondary of the other. Now, as when in the position shown in Fig. 7, this distance is only slightly greater then the span of one commutator segment, it is evident that lessening this distance will allow of one segment being under *both* one of the positive and one of the negative brushes during a part of a revolution, which *short-circuits* the armature, reducing the difference of potential between the brushes (momentarily) to zero.

As the field magnets are in series with the armature, their great self-induction prevents the strength of the current falling to zero, its fluctuations being comparatively small. At the same time, the self-induction of the armature coils prevents any excessive flow of current from one to the other through this short circuit; for, there being two places where the short circuit occurs, i. e., between brushes *1* and *4* and *2* and *3*, and there being three commutator segments, it is evident that six short circuits occur during every revolution, and if the armature is revolving at 850 revolutions per minute, there are $6 \times 850 = 5{,}100$ short circuits every minute, so that each lasts only an extremely short time.

As the distance between the brushes of a set is increased, each short circuit is kept up for a slightly longer time. It will be seen that this momentary reduction of the difference of potential between the brushes to zero reduces its effect in sending a current through the circuit, although its maximum value is not much reduced; so that by shifting the brushes at the proper time, the current in the external circuit can be kept at a constant strength, in spite of variations in the external resistance.

This shifting of the brushes is done automatically by the following apparatus: The primary and secondary brushes are mounted on separate rocker-arms, which are connected together by a system of levers, so that when the primary brushes are shifted back, the secondary are moved ahead. The amount of movement of the secondary brushes is very little, being for the purpose of following the line of maximum action, which moves ahead slightly at light loads (low E. M. F.). A large magnet attached to the frame of the machine has attached to its keeper a lever, which is connected to the rocker-arm that carries the primary brushes, so that when the keeper of the magnet is pulled up, the primary brushes are shifted back and the secondary ahead, thus reducing the effective difference of potential between the brushes, as explained. The current for operating this regulating magnet is supplied by the main current, but it is not continually in circuit, being cut in or out, as occasion requires, by a controlling magnet that is placed on the wall of the room at some convenient place.

22. Fig. 8 is a diagram of the connections used in this apparatus. *R* represents the regulating magnet and *K* its keeper, which is connected to the rocker-arms by a lever (not shown), as described. *C*, *C* represent the coils of the controlling magnet, which are stationary, and *D*, *D* represent the cores of this magnet, which are movable. Their weight is partly counterbalanced by the spring *s*, the tension of which is adjusted by means of the nuts at *N*. Attached to these cores is a contact point, which touches a stationary contact piece at *B*. The connections being as represented, + being the positive terminal of the dynamo, it is evident that when the two contact points at *B* are touching, the regulating magnet *R* is short-circuited, the current flowing from + to p^2, thence to P^2, thence through the contact points at *B* to *P*, thence through coils *C*, *C* to P^1, and out to the line. Now, if this current exceeds a certain strength, the pull of the coils *C*, *C* on the cores *D*, *D* becomes sufficient to raise them, breaking the contact at *B*. This

forces the current around from p^2 through the regulating magnet R to P, thence to P^1, where it passes out to the line as before. The regulating magnet then attracts and pulls up its keeper K, which in moving shifts the brushes and reduces the current as described.

When the current is reduced to its normal value, the cores of the controlling magnet descend, and contact is made at B, which short-circuits the regulating magnet and allows its keeper to drop. This shifts the brushes again so as to increase the current. This action is kept up, so that the cores of the controlling magnet and the brushes of the machine are continually in slight motion. In order to prevent the self-induction of the regulating magnet causing a serious spark at B when the contact is broken, a shunt of high resistance is permanently connected around the break at B, as represented at r. An induced E. M. F. is set up in the regulating magnet R whenever the circuit is opened at B, for this suddenly diverts the main current through the regulating magnet, whose momentary self-induction opposes the current, forcing it along by way of p^2, P^2, and the resistance r to the line. If the resistance were not there, the current would cross the air gap at B, making a destructive spark.

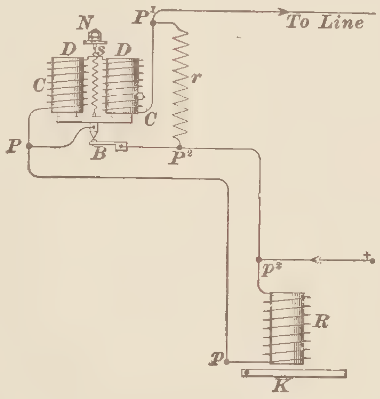


FIG. 8.

The space between the ends of the commutator segments being small, some device is necessary to prevent the spark that occurs when a segment passes from under one of the secondary brushes continuing to pass from segment to segment, for that would permanently short-circuit the machine. This device consists of a small rotary blower, which is situated between the commutator and the bearing. This

blower is so arranged as to deliver a puff of air right at the end of the secondary brushes at the moment that the spark occurs, so that it is immediately broken and does no damage.

The adjustment of the commutator, brushes, air blast, etc. of this machine requires considerable attention in order that the machine should run well. The manufacturers supply printed matter with each machine, giving full particulars of these operations, hence they need not be taken up here.

THE OUTPUT OF CONSTANT-CURRENT DYNAMOS.

23. From the nature of the output, the heat losses in constant-current dynamos are practically constant at all loads. In some of the open-coil machines, the local currents that circulate in the coils at light loads may be of greater strength than the current in the external circuit, so that the heating of the armature may be even greater at light loads than at full load. It is evident, however, that the heating is not the factor that limits the load, nor is the sparking, since the machine must be so designed that the sparking is the same at all loads. The factor of the load that varies is the E. M. F., so that when this has reached its highest value, any further increase in the external resistance can only reduce the current, since the E. M. F. cannot increase farther. The maximum E. M. F. that the machine can give determines then the limit of its output.

Constant-current machines may be rated according to their output, expressed in kilowatts (1 kilowatt being 1,000 watts), as are constant-potential machines; but as they are almost invariably used for operating *arc lamps*, they are usually rated according to the maximum number of lamps for which they can supply current. The strength of the current most used is from 9.5 to 10 amperes, 9.6 being the standard adopted by many manufacturers. With this current, each arc lamp requires from 45 to 50 volts. All lamps being connected in series, this makes the maximum E. M. F

of, for example, an 80-light dynamo $80 \times 50 = 4{,}000$ volts. Machines are built of 150 lights capacity, but the sizes most generally used have a capacity of from 50 to 80 lights. When enclosed arc lamps are used a current of 6.6 amperes is common, the voltage per lamp being from 70 to 80 volts.

Almost all the regulating devices used are practically independent of the speed, so that they will maintain the current constant when the speed varies somewhat, if the variations are not too sudden. Any reduction in the speed, however, reduces the maximum E. M. F. and output that can be obtained, and, conversely, an increase in the speed will increase the possible output.

DIRECT-CURRENT ELECTRIC MOTORS.

PRINCIPLES OF OPERATION.

24. Electric motors designed to be operated by continuous current were in use before the dynamo was invented. Such motors were operated by batteries, and usually were made up by arranging pieces of iron so that they would be successively attracted by electromagnets, and thus give rise to motion. Several styles of such motors were made, and although they operated after a fashion, they ultimately proved failures, and attempts to utilize electricity as a source of mechanical energy by this means proved fruitless. The cause of this failure was twofold. In the first place, batteries proved to be a very expensive means of generating the current necessary, and, secondly, motors built on the lines indicated above were very inefficient, delivering only a very small amount of power at the pulley compared with the amount of power supplied to them. The invention of the dynamo afforded a cheap and convenient means of generating current, so that after its invention attention was again given to electric motors. Soon after the invention of the dynamo, it was found that the same machine that operated as a dynamo could also be run as a motor if it were fed with

current from an outside circuit; in other words, that the ordinary continuous-current dynamo was reversible in its action. It was also found that an electric motor designed on the same lines as the dynamo would convert electrical energy into mechanical energy quite as efficiently as the dynamo would perform the reverse operation. Direct-current motors came into rapid use for transmitting power, and although the alternating-current motor is beginning to take their place in some cases, there are still large numbers of them used. The most extended use of direct-current motors at present is probably in connection with street railways, the alternating current having been used very little for this purpose as yet.

DYNAMOS AND MOTORS COMPARED.

25. A dynamo may be defined as a machine for the generation of an electromotive force and current by the motion of conductors through a magnetic field. This motion and the force necessary to maintain it must be supplied by a steam engine or other source of power. On the other hand, a motor may be defined as a machine for supplying mechanical power when supplied with an electric current from some outside source. The motion and the force necessary to maintain it is, in this case, supplied by the reaction between the current flowing in a set of conductors and the magnetic field in which the conductors are placed.

26. As far as the electrical features of a continuous-current motor are concerned, they are almost identical with those of the continuous-current dynamo. The differences in the two that occur in practice are very largely differences in mechanical details that are necessary to adapt the motor to the special work that it must do. This is notably the case with street-railway motors, motors used in mining and hoisting work, etc. The class of work that such motors have to perform renders it necessary that they should be enclosed as much as possible. No matter what

may be the mechanical design of such motors, they all consist of the same essential parts as the dynamo, namely, field magnet, and armature with its commutator, brush holders, etc.

ACTION OF MOTOR.

27. It is necessary to consider carefully the forces acting in a motor, in order to understand clearly the behavior of different kinds of motors when operated under given conditions. In order to do this, we will consider the force acting on a conductor that is carrying a current

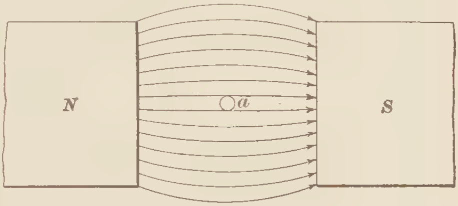


FIG. 9.

across a magnetic field. Suppose the arrows, Fig. 9, represent magnetic lines of force flowing between the pole faces of the magnet *N S*, and let *a* represent the cross-section of a wire lying at right angles to the lines. So long as no current flows through the wire,

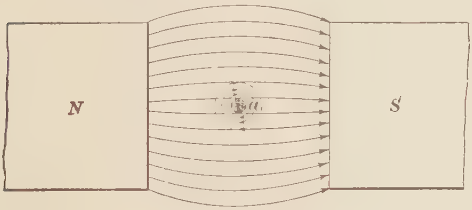


FIG. 10.

the field will not be distorted, and there will be no tendency for the wire to move. If the ends of the wire are connected to a battery so that a current flows, say, down through the paper, this current will tend to set up lines of force around the wire, as shown by the dotted circles in

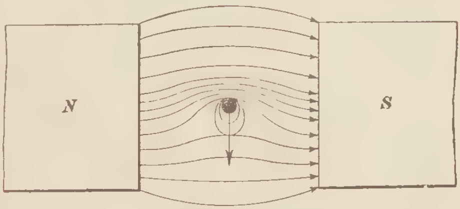


FIG. 11.

Fig. 10. It will be noticed that these lines tend to oppose

the original field below the wire and make it more dense above the wire. The resultant effect is that the field is distorted, as shown in Fig. 11, and the lines of force from N to S that tend to straighten themselves out force the wire downwards.

28. The action described in the simple case just given is essentially that which takes place in an electric motor. The magnetic field is supplied by the field magnet, which is excited by means of current taken from the mains to which the motor is connected. Current from the line is led into the armature windings by means of the commutator and brushes, and this armature current reacts on the field, thus driving the armature around. The commutator keeps the relation between the current in the conductors and the field such that the twisting force, or *torque*, acting on the armature is continuous, and a uniform rotary motion is the result. The effort exerted by the reaction between the field and the current in each individual conductor may be quite small; but it must be remembered that the armature is usually provided with a large number of conductors, so that the total resulting torque may be quite large.

29. By referring to Fig. 11, it will be seen that in a motor the conductors are *forced* across the field by the reaction of the armature current on the field. That is, *the force exerted by the magnetic field on the armature conductors of a motor is in the same direction as the motion of the armature.* This force is used for doing mechanical work. Compare this with the action of a dynamo. The dynamo armature is driven by means of a steam engine or other source of power, and the armature conductors are made to cut across the magnetic field, this motion causing the generation of an E. M. F. When the outside circuit is closed, so that current flows through the armature conductors, this current reacts on the field in such a way as to *oppose* the motion of the armature. The more current the dynamo supplies, the greater is this opposing torque action between armature and field and the more work must the

steam engine do to keep the dynamo operating. In the case of a motor, the greater the load applied to the pulley, the greater must be the torque action between the armature and field to keep up the motion, and the greater the amount of current that must be supplied from the line. It is thus seen that as regards the torque action between the armature and field, the motor is just the opposite of the dynamo, the force action in the former case being *with* the direction of motion and in the latter case *against* it.

COUNTER E. M. F. OF MOTOR.

30. It was shown, in connection with the study of the theory of the dynamo, that whenever a conductor is moved in a magnetic field so as to cut lines of force, an E. M. F. is induced in the conductor. In the case of a dynamo, an E. M. F. is generated in this way, and this E. M. F. is made use of to set up currents in outside circuits. In other words, the E. M. F. is the *cause* of the flow of current, and consequently the E. M. F. is in the same direction as the current.

In a motor we have all the conditions necessary for the generation of an E. M. F. in the armature; that is, we have an armature revolving in a magnetic field and conductors cutting across lines of force. It is true that, in the case of a motor, the armature is not driven by a belt as in the case of a dynamo, but is driven around by the force action between the field and armature. This, however, makes no difference as far as the generation of an E. M. F. is concerned.

When a motor is in operation, there must be an E. M. F. generated in its armature, and for the present we will term it the **motor E. M. F.** Take the simple case shown in Fig. 11—as the conductor is forced down, it will pass across the magnetic field and an E. M. F. will be induced in it. Also, by applying the rule for determining the direction of the induced E. M. F., we see that it must be directed upwards, that is, towards us along the conductor (the direction of motion being down and the direction of the field from left to right). The *current* flowing in the conductor is

flowing from us, or is being opposed by the motor E. M. F. We may state, then:

In an electric motor, the E. M. F. generated in the armature is opposed to the current that is flowing through the armature. Owing to the fact that the motor E. M. F. is opposed to the current, it is commonly spoken of as the **counter E. M. F.** of the motor. It is important that the student should clearly understand the generation of this counter E. M. F. and its relation to the current. As regards the generation of E. M. F., the motor is the opposite of the dynamo, as in the latter case the E. M. F. is always in the same direction as the current.

31. In order that a current may be sent through the armature of a motor, the E. M. F. of the dynamo supplying the current must be greater than that of the motor. Suppose a dynamo A, Fig. 12, is supplying current to the motor B. Let E be the E. M. F. maintained between the mains by the dynamo A. We will suppose E to be kept constant independent of the current delivered. The motor when running will generate a certain counter E. M. F. which we will call E_m. Part of the line pressure will be used in overcoming the counter E. M. F. E_m of the motor and the remainder in overcoming the resistance of the armature.

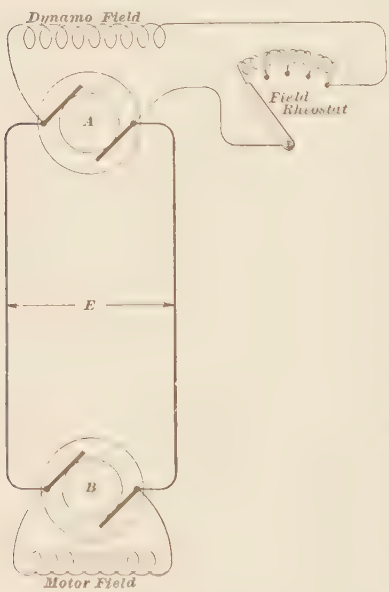


FIG. 12.

If C is the current flowing through the armature, we must have the relation

$$E = E_m + C R_a, \qquad \textbf{(1.)}$$

where R_a is the resistance of the armature. This must hold true for any value of the current. If the field coil were connected in series with the armature instead of in shunt as shown, a small part of E would also be required to overcome the resistance of the field winding.

32. It is evident from formula **1** that if the current flowing is very small (which is the case if the load on the motor is very light), the counter E. M. F. E_m is nearly equal to the E. M. F. E maintained between the lines by the dynamo. If E and E_m were exactly equal, no current would flow in the circuit. In practice, E_m never becomes quite equal to E, because it always takes a small amount of current to run a motor even if no load is applied to the pulley. There is always, therefore, a slight amount of the line pressure taken up in overcoming the armature resistance, and E_m is always less than E, as shown by formula **1.**

Since the counter E. M. F. is nearly equal to the applied E. M. F., it is only necessary for it to vary a small amount to vary the current within wide limits. For example, if the resistance of a certain armature is 1 ohm and it is supplied with current at a constant potential of 250 volts, then, when a current of 10 amperes is flowing through it, the drop is $10 \times 1 = 10$ volts, and the counter E. M. F. is $250 - 10 = 240$ volts. Now, if the current is reduced to 1 ampere, the drop is $1 \times 1 = 1$ volt, and the counter E. M. F. is $250 - 1 = 249$ volts; that is, the counter E. M. F. varies only $\frac{9}{240}$, or 3.75 per cent., while the current varies $\frac{9}{10}$, or 90 per cent.

TORQUE.

33. As already stated, the reaction between the currents in the armature conductors and the magnetic field produces a twisting action which is called the **torque.** This torque may be present whether the motor is running or not because, even if the armature is held from turning, it is evident that a strong twisting effort or tendency to turn may still be exerted.

The amount of the torque—which is usually expressed in **pound-feet**, that is, a certain number of pounds acting at a radius of a certain number (usually 1) of feet—depends on (1) the strength of the field; (2) the number of conductors; (3) their mean distance from the axis of the armature; and (4) the amperes in each conductor. In any given machine, the second and third conditions are constant, so that the torque depends on the strength of the field and the current.

34. The torque of a motor is equal to the number of *pounds pull* exerted at the circumference of the pulley or at the pitch circle of the gear multiplied by the radius of the pitch circle of the pulley or gear. This torque is the same for a given current, whatever may be the speed. But for each revolution of the motor, the point at which the pull is exerted moves through a certain distance (that is, once around the circumference of a circle) equal to 3.1416 times the diameter of the circle, or to $2 \times 3.1416 \times$ the radius of the circle, at the circumference of which the pull is considered to act.

Each revolution of the motor, then, when a certain torque is exerted, corresponds to a certain number of *foot-pounds of work done.*

This number of foot-pounds will be the same for a given torque, whatever may be the radius of the circle through which the point of application of the pull moves; for, if a radius be taken that is twice as long as another, the distance moved through will be twice as great, but the pull in pounds that the motor is capable of exerting at twice the former radius will be only half as much, so that their product remains the same. For the sake of uniformity, a standard radius of 1 foot is used, and the torque is expressed in *pounds at 1 foot radius.*

It will be noticed that the words *moment* and *torque* have the same meaning.

The foot-pounds of work done in each revolution and the number of revolutions per minute being known, the

foot-pounds of work done per minute, and from that the horsepower, may be found by the following formula:

$$\text{H. P.} = \frac{2 \times 3.1416\, T S}{33{,}000} = .0001904\, T S, \qquad (2.)$$

in which T represents the pull in pounds at 1 foot radius, that is, the torque; S the number of revolutions per minute, and H. P. the horsepower.

Hence, *to obtain the horsepower of a motor, multiply 3.1416 by 2, this product by the torque* (*expressed in pounds at 1 foot radius*), *and this product by the number of revolutions per minute; divide the final product by 33,000.* An alternative method is to use the constant .0001904, and multiply this by the product of the torque and speed expressed as above.

If the H. P. and the torque are known, the number of revolutions per minute may be found from a modification of the above formula:

$$S = \frac{33{,}000 \text{ H. P.}}{2 \times 3.1416\, T} = \frac{\text{H. P.}}{.0001904\, T}. \qquad (3.)$$

Or, if the H. P. and the number of revolutions per minute are known, the torque may be found from the formula

$$T = \frac{33{,}000 \text{ H. P.}}{2 \times 3.1416\, S} = \frac{\text{H. P.}}{.0001904\, S}. \qquad (4.)$$

35. Fig. 13 illustrates a method of measuring the torque of a motor by means of a **Prony brake.**

This brake consists of two blocks of wood B, B made to fit the surface of the pulley P. These two blocks bear on the pulley on opposite sides, as represented, and their pressure on the pulley is regulated by means of the thumb-nuts N, N on the bolts that hold the two parts of the brake together.

The lower of the two blocks of wood is extended in both directions, forming on the one side an arm A that presses on the platform of a set of scales S, and on the other a place where weights W may be placed to balance the weight

of the arm *A*. A spike, or lagscrew, *C* should be driven through the end of the arm *A* to better locate the point where it presses on the scale platform.

If the pulley *P* is revolved in the direction indicated by the arrow, the friction of the brake will cause it to tend to rotate with the pulley, which will cause the spike in the end of the arm *A* to press down on the scale platform, and the amount of this pressure may be weighed by the scale beam. The *product* of the number of pounds pressure and the *horizontal* distance *R* between the point *C* and the center

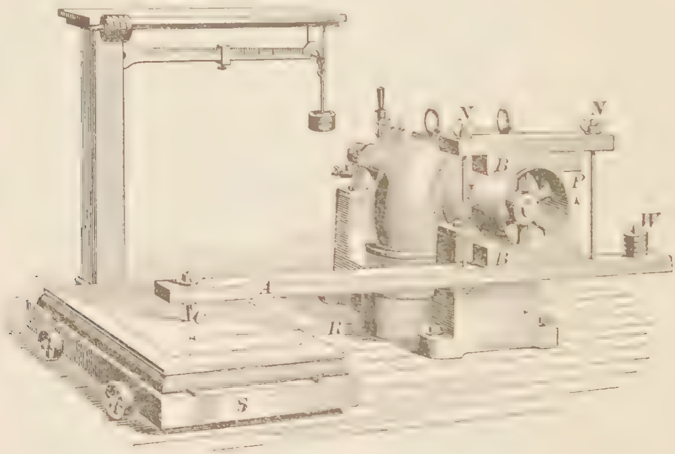


FIG. 13

of the pulley in feet, will give the torque in *pound-feet*. Then, if the number of revolutions per minute of the motor is counted, the horsepower absorbed by the friction of the brake, that is, the output of the motor, may be calculated by formula **2**. If at the same time the amperes input and the voltage at the motor terminals are measured, their product will be the watts input, and by reducing the output and the input to the same units, the efficiency may be calculated by dividing the output by the input.

36. The following example shows the application of the above rules and method of testing motors:

EXAMPLE.—A given shunt-wound motor is designed for an output of 10 H. P. and to be run on a constant-potential circuit of 230 volts. When driving a certain piece of machinery, it requires an input (to both field and armature) of 35 amperes at 230 volts. It is desired to find the actual horsepower required to drive this machinery. The motor is disconnected from its load and a Prony brake rigged up as shown in Fig. 13. The thumbnuts are screwed up until an ammeter in the motor circuit indicates that 35 amperes are flowing through the motor circuit, and the voltage at the terminals is found to be 230 volts. Under these conditions, the pressure on the scale platform is found to be 24 pounds and the speed of the motor 800 revolutions per minute. The horizontal distance between the center of the shaft and the point where the brake arm rests on the scales is 30 inches. What is the output of the motor at this load in horsepower, and what is its efficiency?

SOLUTION.—The distance R, Fig. 13, being 30 inches, or $2\frac{1}{2}$ feet, and the pressure on the scales being 24 pounds, the torque of the motor is $24 \times 2\frac{1}{2} = 60$ pound-feet. Substituting this value for T, and 800 for S, in formula **2**, gives

$$\text{H. P.} = \frac{2 \times 3.1416 \times 60 \times 800}{33,000} = \frac{301,593.6}{33,000}.$$

NOTE.—As the instruments used are liable to slight errors, four figures (other than the zeros) left in the calculations will be near enough; if the last figure dropped is equal to 5 or more, the last figure *kept* should be increased 1.

Then, $\frac{301,600}{33,000} = 9.1393$, or 9.139 H. P. is the output of the motor. Ans.

The input is $35 \times 230 = 8,050$ watts. Reducing 9.139 H. P. to watts gives $9.139 \times 746 = 6,817.694$, or 6,818 watts. Then, the efficiency

$$\mathsf{E} = \frac{6,818 \times 100}{8,050} = 84.7 \text{ per cent.} \quad \text{Ans.}$$

37. The loss represented by the difference between the input and the output is made up of exactly the same elements as the total loss in dynamos; that is, mechanical friction, core loss, field loss, and armature loss. As in dynamos, the armature loss and field loss may be calculated from the resistance of the armature and field coils, remembering that in a shunt motor the *armature* current is *less* than the *total* current, since the field circuit is in parallel with the armature. The core loss and friction taken together evidently equal the difference between the total loss and the sum of

the armature and field losses; they cannot be separated without special tests being made.

In a shunt motor, the field loss, core loss, and friction are all practically constant at all loads, since the speed is nearly constant. This being the case, the *watts required to run the motor without any external load whatever* is a measure of these losses plus a certain small amount of armature $C^2 R$, which may be calculated, though it is usually small enough to be neglected without much error. This being the case, the output which a motor will give at any given input will be very closely equal to that input less the watts required to run the motor free, and also less the armature $C^2 R$ loss at the given input; from this the efficiency may also be calculated. To determine the efficiency of the motor at any load within its rated capacity, then, it is only necessary to carefully measure its input at no load (running *light* or *free*), and to make the above calculation. This, however, will give no idea of its performance as to heating and sparking, under the calculated load, so that the Prony-brake test is more satisfactory.

For example, a certain shunt-wound motor requires a current of 1.2 amperes at 500 volts when running *free*, i. e., without external load. Its armature resistance is 2.4 ohms and its field resistance is 834 ohms. Its field current is then $\frac{500}{834} = .5995$ ampere, or, say, .6 ampere. Its armature current is then $1.2 - .6 = .6$ ampere, and its armature loss only $.6 \times .6 \times 2.4 = .864$ watt, which may be neglected.

The input amounts to $1.2 \times 500 = 600$ watts, of which the field loss is $.6 \times 500 = 300$ watts.

If the efficiency when taking 10 amperes at 500 volts is wanted, it may be found from the above figures, as follows: Total input, $10 \times 500 = 5{,}000$ watts. Field loss and core loss and friction combined amount to 600 watts, as found above. The armature loss amounts to $9.4 \times 9.4 \times 2.4 = 212.06$, or, say, 212 watts. The total loss is then $600 + 212 = 812$ watts, so that the output is $5{,}000 - 812 = 4{,}188$ watts and the efficiency $(E) = \frac{4188}{5000} = .837$, or 83.7 per cent. In a similar manner the efficiency at any other input, or the input required for any given output, may be found.

The input, and consequently the output, of constant-potential motors is limited by the same factors that limit the output of dynamos, namely, heating and sparking.

In motors, as the direction of the current for the same direction of the lines of force of the field and of rotation is *opposite* to that in a dynamo, the armature reaction shifts the neutral space in the opposite direction, that is, *backwards*, *against* the direction of rotation. Consequently the brushes of a motor must be shifted *backwards* as the load increases.

CLASSES OF MOTORS.

38. Continuous-current motors, like dynamos, are generally classed according to the methods adopted for exciting the field magnets. This naturally divides continuous-current motors into the following classes:

(1) Shunt-wound; (2) series-wound; (3) compound, or differentially and accumulatively, wound.

Motors may also be operated with separately excited fields, but this is seldom done in practice. By far the larger part of the motors in use belong to the first two classes, the third class being used only to a limited extent. Differentially wound motors are used in some cases where very close speed regulation is required, and motors with a combination of series and shunt windings are used to some extent for the operation of electric vehicles. Nearly all motors are operated on *constant-potential* circuits, the voltage across the terminals being maintained constant or nearly so by the dynamo supplying the system and the current taken by the motor varying with the load. In a few cases motors are operated on *constant-current* arc-light circuits, but their use is very limited. In this case the current through the motor remains constant, and the voltage across its terminals increases with the load.

Shunt motors are used to drive machinery that requires a nearly constant speed with varying loads or that would be damaged if the speed should become excessive, such as

ordinary machinery in shops and factories, pumps, etc. Series-wound motors are used on street cars, to operate hoists, etc., where the torque required at starting and getting quickly up to speed is much greater than the normal amount and where large variations in speed are desired.

SHUNT-WOUND MOTORS.

39. Outside of railway work, the shunt motor is more largely used than any other type because of the valuable speed-regulating qualities that render it well adapted for the operation of all kinds of machinery. The shunt-wound motor is identical, so far as its electrical construction is concerned, with the shunt-wound dynamo. These motors are operated on constant-potential systems, the motor being connected directly across the mains when running, as shown in Fig. 14, where A is the armature and F is the field. If E, the E. M. F. between the mains, is maintained constant, the current flowing through the shunt field will be constant. The field coils will, therefore, supply the same magnetizing force, no matter what current the armature may be taking from the mains. The strength of field would be practically constant if there were no demagnetizing action of the armature. Take the case where the motor is running free and the only load that the armature currents have to overcome is the friction and other losses within the armature. The amount of energy that the motor armature consumes will just be sufficient to counterbalance these losses, and the armature will run up to a speed such that the counter E. M. F. will allow just sufficient current to flow to supply this loss of energy. Since this current is very small in a good motor, the counter E. M. F. when the motor is running light is very nearly equal to the line E. M. F. E.

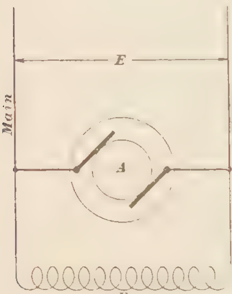


FIG. 14.

40. Action of Shunt Motor.—When a load is applied, the motor must take sufficient current to enable the armature to produce a torque sufficient to carry the load. In order to allow this current to flow, the counter E. M. F. must be lowered slightly, and as the field is nearly constant, this means a slight lowering of speed, because the counter E. M. F. E_m for a two-pole motor is given by the expression

$$E_m = \frac{2\,N\,S\,n}{10^8},$$

where N is the total number of lines of force threading the armature, S the number of conductors in series between the brushes, and n the speed in revolutions per second. S and N are practically fixed. At the same time it must be remembered that the armature reaction will make N slightly less when the motor is loaded than when it is not loaded, and this weakening of the field tends to keep up the speed. The net result is, therefore, that a shunt-wound motor operated on a constant-potential circuit falls off slightly in speed as the load is applied, but if the motor is well designed and has a low-resistance armature, the falling off in speed from no load to full load will be very small. It is this speed-regulating feature that makes the shunt-wound motor so widely used. If the load should be accidentally thrown off, there is no tendency to race, and the motor automatically adjusts itself to changes in load without materially changing its speed and without the aid of any mechanical regulating devices.

41. Speed Regulation.—The speed of a shunt-wound motor fed from constant-potential mains may be varied either by cutting down the applied E. M. F. E or by changing the field strength. For any given load the motor has to generate a certain counter E. M. F.

$$E_m = \frac{2\,N\,S\,n}{10^8}$$

Solving this for n, we have

$$n = \frac{E_m\,10^8}{2\,N\,S}. \qquad (5.)$$

It follows from formula **5** that if the field strength N be decreased, the speed n will be increased, the line E. M. F. remaining the same; also, if the field be strengthened, the speed will be decreased. This simply means that with a strong field the motor does not have to run as fast to generate a given counter E. M. F. as it would if the field were weak. The method of regulating the speed of a shunt-wound motor by varying its field strength is sometimes used. It is the most efficient method for regulating speed, as it only necessitates cutting down the small field current by means of a resistance. The method described in the next article is, however, more generally used, though it causes a much larger waste of energy. In using the field method of control, care must be taken to see that the weakest field used will allow the machine to operate without sparking.

42. The speed may also be regulated by leaving the field at its full strength and cutting down the voltage applied to the armature by inserting an adjustable resistance in

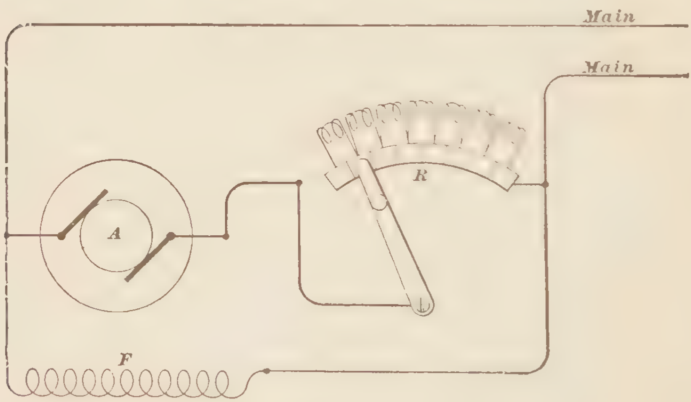


FIG. 15.

series with it. The connections for this method of speed regulation are shown in Fig. 15, the adjustable rheostat R being connected in series with the armature A and the field F connected directly across the mains. This method is

rather wasteful of energy, but it is the one generally used when it is desired to control the speed of a shunt-wound machine. If a shunt-wound motor be overloaded or stalled in any way, the current becomes excessive, and the armature is burned out, unless it is protected by fuses (pieces of soft fusible metal that melt when the current becomes excessive) or other safety device. Care should also be taken never to open the field circuit of such a machine while its armature is connected to the circuit. If the field circuit is opened, the machine is unable to generate any counter E. M. F., and the consequence is a large rush of current through the armature, which is at least apt to burn the commutator, and if not interrupted by means of fuses will in a short time burn out the armature. It is now considered best practice to install a circuit-breaker in preference to fuses for the protection of a motor, especially if the motor is of large size. In some cases both fuses and circuit-breaker are used.

The speed may also be regulated by varying the E. M. F. of the dynamo that supplies the motor. This, however, can only be done in special cases, because if the voltage of the dynamo is varied, it not only affects the motor but all other devices that may be operated from the same dynamo.

SERIES-WOUND MOTORS.

43. These motors are constructed in the same way as series-wound dynamos; that is, the fields are excited by connecting the field coils in series with the armature, so that all the current that the motor takes from the mains flows through the field windings. The most extensive use of these motors is in connection with street railways. They are also used to some extent for operating hoists, cranes, and other machinery of this class that requires a variable speed. Nearly all series-wound motors, like shunt-wound motors, are operated on constant-potential circuits. For example,

the pressure of a street-railway system is maintained approximately constant at 500 volts. Crane and hoist motors are usually operated at pressures of 110, 220, or 500 volts. Series-wound motors are operated to a limited extent on *constant-current* arc-light circuits, but the number so operated is insignificant compared with those operated on constant-potential circuits.

44. Series-Wound Motor on Constant-Potential Circuit.—Let *A*, Fig. 16, represent the armature of a series-wound motor connected in series with the field *F* across the mains, as shown. The pressure between the mains is maintained constant. First, we will consider the case where the motor is running light. Under this condition of load, the motor will take just enough energy from the line to make up for the losses due to friction, core losses, etc. As the armature speeds up, the counter E. M. F. increases and the current rapidly decreases. Now the field is in series with the armature, so that as the current decreases, the field

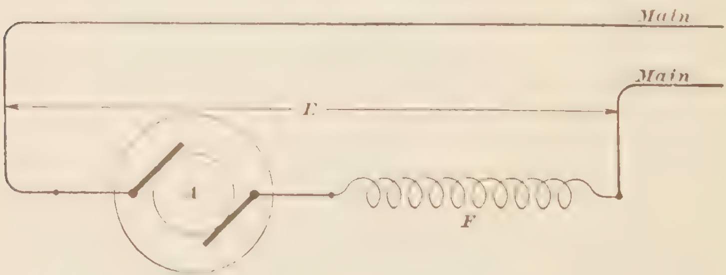


FIG. 16.

strength also decreases and the armature has to run still faster to generate its counter E. M. F., which at no load is just about equal to the E. M. F. between the mains. The current necessary to supply the losses is usually very small if the motor is well designed, consequently the no-load current is very small, and the speed necessary to generate the counter E. M. F. becomes excessively high. In many cases this speed might be high enough to burst the armature.

On account of this tendency to race, it is not safe to throw the load completely off a series-wound motor unless there is some safety device for automatically cutting off the current. Of course in street-railway work there is always some load on the motors, so that no injury from racing is liable to result.

45. When the motor is loaded, the counter E. M. F. decreases slightly, and this allows more current to flow. This current strengthens the field, and a correspondingly strong torque is produced. It should be noted here that the torque of a series-wound motor depends directly on the current that is flowing through it. The torque is proportional to the field strength and the current in the armature, but the field strength in a series-wound motor depends on the current, so that the torque depends only on the current. This quality renders the series-wound motor valuable for street-railway work, as a strong starting torque can be produced by allowing a heavy current to flow through the motor while the car is being started. Since the field strength of a series-wound motor increases as the load is applied, it follows that the speed will decrease with the load and there will be a different speed for each load. This variable speed renders the series-wound motor generally unsuitable for stationary work, such as operating machinery, etc., but is an advantage for street-railway work where a wide range of speed is desired. Series-wound motors are more substantial and cheaper to build than shunt-wound motors, on account of the fine field winding required by the latter. The field coils of series-wound motors consist of a comparatively small number of turns of heavy wire, making a coil that is less liable to burn-outs than the fine-wire shunt coils and better fitted to stand the hard service connected with all street-railway work.

If a series-wound motor be connected across the mains, the current that flows must pass through the field as well as through the armature, thus giving a good field for the armature currents to react on and produce the required

starting torque. When a shunt-wound machine is used, the field must first be connected to the mains and the current then allowed to flow through the armature. If this is not done, the current will all flow through the low-resistance armature in preference to the high-resistance field when the motor is first connected, and a very small starting torque will be the result.

46. Speed Regulation.—The speed of a series-wound motor may be regulated either by varying the strength of the field or by inserting a resistance in series with the motor. The field strength may be regulated by having the field coils wound in a number of sections and cutting these in or out, thus varying the effective number of turns. Another method is to shunt the fields by an adjustable

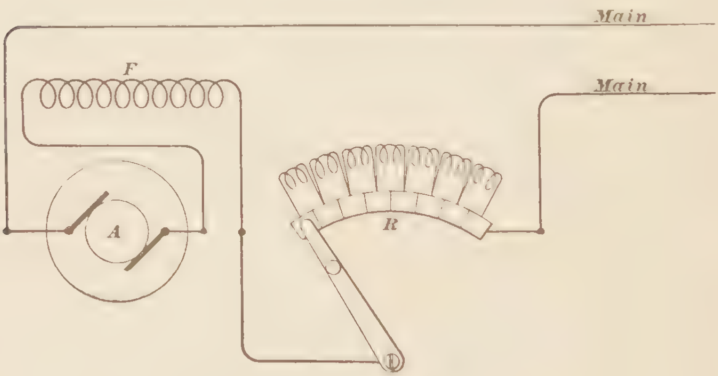


FIG. 17.

resistance, thereby varying the amount of current that flows through the series coils. Both these methods have been used for controlling the speed of street-car motors. In the resistance method of control, an adjustable rheostat is connected directly in series with the motor, as shown in Fig. 17, thus cutting down the E. M. F. across the motor terminals. This method has also been used quite largely on street cars and also for crane and hoist motors.

DIFFERENTIALLY WOUND MOTORS.

47. These motors are essentially the same in construction as the compound-wound dynamo, except that the series coils are connected so as to oppose the shunt coils instead of aiding them as in the dynamo. The object of this arrangement is to secure constant speed when the voltage of the dynamo supplying the motor is constant. The series coils decrease the field strength slightly, and by thus weakening the field lower the counter E. M. F. sufficiently without decreasing the speed. These motors are not used as generally now as they once were, because it is found that a well-designed shunt-wound motor will give sufficiently close speed regulation for all practical purposes. Fig. 18 shows the connections of a differentially wound motor, the coils being intended to represent windings in opposite directions, one right-hand, the other left-hand.

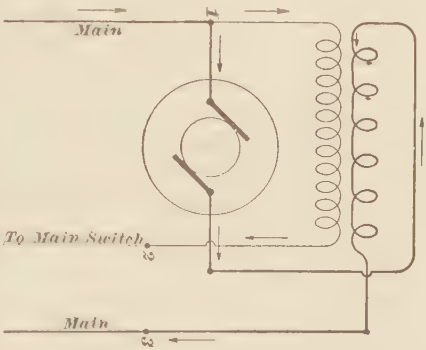


FIG. 18.

ACCUMULATIVELY WOUND MOTORS.

48. When a motor is provided with a compound winding and the series coils are so connected that they *aid* the shunt coils, the motor is said to be *accumulatively wound.* This arrangement is sometimes used when it is necessary to have the constant-speed advantage of the shunt-wound motor, and at the same time have the strong starting torque of the series-wound motor. Motors of this kind are used considerably for operating printing presses or other work when the starting friction of the machine is large

AUXILIARY APPARATUS.

STARTING RHEOSTATS.

49. When motors are operated on constant-potential circuits, it is necessary to insert a resistance in series with the armature when starting the motor. Of course, in the case of a series-wound motor, this starting resistance is also in series with the field. The resistance of a motor armature is very small in any type of motor, and in the case of a series-wound motor the field resistance is also small, so that if the machine were connected directly across the circuit while standing still, there would be an enormous rush of current, because the motor is generating no counter E. M. F. Take, for example, a shunt-wound motor of which the armature resistance is .1 ohm. If this armature were connected across a 110-volt circuit while the motor was at a standstill, the current that would flow momentarily would be $\frac{110}{.1} = 1{,}100$ amperes, the amount being limited only by the resistance of the armature. In the case of a series-wound motor, the rush of current would not be quite as bad, as the field winding would help to choke back the current, but in either case it is necessary to insert a resistance and gradually cut it out as the motor runs up to speed and generates a counter E. M. F. that is able to regulate the current.

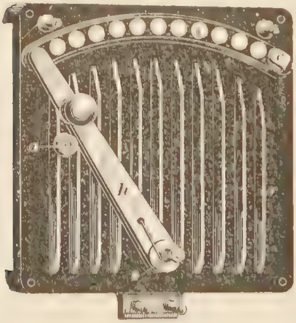


FIG. 19.

50. The starting rheostat, or **starting box,** as it is often called, is simply a resistance divided up into a number of sections and connected to a switch, by means of which these sections can be cut out as the motor comes up to speed. When the motor is running at full speed, this resistance is completely cut out, so that no energy is lost in it

Fig. 19 shows a simple form of motor-starting rheostat, the resistance wire in this particular type being bedded in enamel on the back of an iron plate, while the ribs *r* on the front are intended to present additional cooling surface to the air. Starting rheostats are not designed to carry current continuously, and should therefore never be used for regulating the speed of the motor. The resistance wire is made of such a size as to be capable of carrying the current for a short time only, and if the current is left on continuously the rheostat will be burned out. The handle *h* of the rheostat shown is provided with a spiral spring *s*, tending to hold it against the stop *a*, which makes it impossible to leave the contact arm on any of the intermediate points. On the last point a clip *c* is placed to hold the arm of the rheostat.

SHUNT-WOUND MOTOR CONNECTIONS.

51. The method of connecting up a shunt-wound motor to constant-potential mains is shown in Fig. 20. The lines leading to the motor are connected to the mains through a fuse block *D*, from which they are led to a double-pole knife switch *B*. One end of the shunt field *F* is connected to terminal *1* of the motor, and one brush is also connected to the same terminal. The other field terminal is connected to the motor terminal *2*,

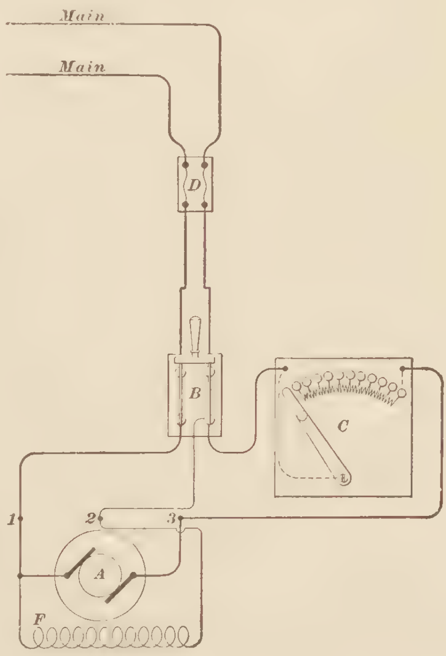


FIG. 20.

and the other brush leads to the third terminal *3*. One side of the main switch connects to terminal *1*; the other side connects to *3 through the starting rheostat C*. Terminal *2* connects to the same side of the switch as the starting rheostat. It will be seen from the figure that as soon as the main switch is closed, current will flow through the

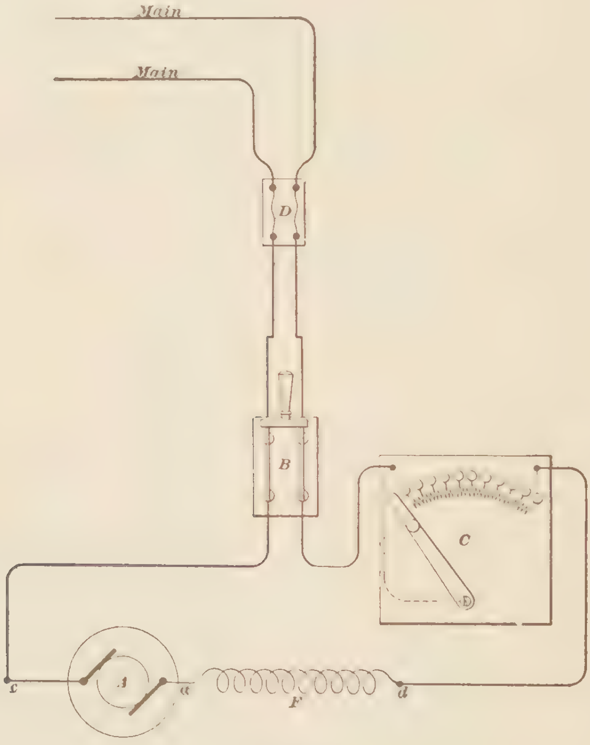


FIG. 21.

field *F*, and thus magnetize it before any current flows through the armature *A* (the first contact on the rheostat being a dead point). When the rheostat arm is moved over, current flows through the armature, and a strong starting effort is produced, because the field is already magnetized. The handle is then moved over slowly and left on the last

point when the motor has attained its full speed. If the motor is at all large or if there is liability of its being subjected to frequent overloads, it is preferable to use a circuit-breaker instead of the fuse block *D*. Circuit-breakers are more reliable and less troublesome than fuses.

SERIES-WOUND MOTOR CONNECTIONS.

52. The connections for a series-wound motor are shown in Fig. 21. Connection is made to the mains through a switch and fuse block as before. The motor connections are somewhat simpler than in the last case, one terminal of the armature *A* being connected at *a* to one terminal of the field, *c* and *d* forming the two terminals of the motor. The starting rheostat *C* is simply connected in series with the armature, as shown. When a current flows through the armature, the same current also flows through the field, so that there is always a magnetic field present to produce the required starting torque. On account of the field winding acting to a certain extent like a starting resistance, series-wound motors do not require as large an amount of resistance in the starting rheostat as shunt-wound motors. This feature is of value in street-railway work, as it permits the use of a less bulky starting resistance than would otherwise be required.

AUTOMATIC SWITCHES.

53. When the simple form of starting box is used, it is necessary to see that the handle is moved back to the off position every time that the motor is shut down or the current cut off in any way. If this is not done and the switch is thrown in, on starting up again, with the resistance all out of the circuit, there will result a heavy rush of current. In order to obviate this, motors are now usually provided with automatic boxes, the switch lever of which automatically

flies to the off position when the current is shut off. They are also generally provided with an arrangement for throwing back the switch lever, and thus breaking the circuit, when the motor is overloaded. Fig. 22 shows the arrangement of an automatic box of this type, which will serve to illustrate the action of most of these automatic starting rheostats. The resistance is connected between the contact points, as shown, the arm being shown in the running position

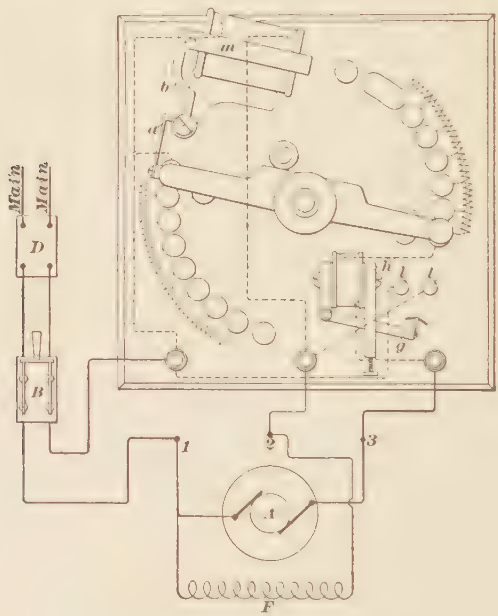


FIG. 22.

with the resistance all cut out. The contact arm is moved over against the action of a spiral spring in the hub and is held in position by a catch *a*, which fits into a notch in the hub of the lever *b*. This lever carries an armature that is held down against the action of a spring by the magnet *m*. The exciting coil of this magnet, in the case of a shunt-wound machine, is connected in series with the field; in the case of a series-wound machine, it is wound with heavy wire and

connected in series with the motor. If the current is cut off in any way, the magnet releases the armature and the switch lever flies back to the off position.

54. Fig. 22 also shows a device for protecting the motor against overloads. It consists of an electromagnet, the coil of which is connected in series with the armature *A*. This magnet is provided with a movable armature *g*, the distance of which from the pole *h* may be adjusted by a screw. When the current exceeds the allowable amount, the armature is lifted, thus making connection between the pins *l*, *l*. This connection short-circuits the coil of the magnet *m* and the lever goes to the off position.

REGULATING RHEOSTATS.

55. Rheostats used for regulating the speed by being placed in the armature circuit must be designed to carry the current continuously without overheating. These rheostats must, therefore, be made much larger than starting boxes, which carry the current for a short time only. Such rheostats were used largely at one time for the control of street cars, but have now been displaced, owing to the adoption of more economical methods. All regulating rheostats, starting boxes, etc. should be installed in connection with motors in accordance with the rules of the Board of Fire Underwriters. This also applies to the size of wire that should be used for connecting up the motors and the installation of the motors themselves.

METHODS OF REVERSING MOTORS.

56. It is necessary for some kinds of work to have a motor so arranged that its direction of rotation may be readily reversed. This is especially the case with street-car motors, motors for electric vehicles, etc. If the student

will refer to Figs. 9, 10, and 11, he will readily see that if the direction of the current in the wire *a* be reversed while the field is left unchanged, the direction of motion will be reversed. Also, if the direction of the current in the wire is left unchanged and the field reversed, the direction of motion will be reversed. If both current and field be changed, the direction of motion will remain unchanged. It follows, therefore, that if we wish to change the direction of rotation of a given motor, we must change either the direction of the current through the armature and leave the field the same, or change the direction of the current through the field and leave the armature current the same. If both are changed at the same time, the direction of rotation will not be altered.

57. A shunt-wound motor may be easily reversed by reversing its field connections. Suppose a shunt-wound motor to be connected as shown in Fig. 23, and that it runs in the direction indicated by the arrow. The line is connected to terminals *1* and *3* and the field to terminals *1* and *2* when the motor is in operation and the starting resistance cut out. It is evident that reversing the line terminals *1* and *3* will not reverse the motor, because the current will be reversed in both armature and field. If, however, the field connections to *1* and *2* are interchanged, the current will be reversed through the field, while it will remain unchanged in the armature and the direction of rotation will be reversed. It is also evident that if the armature terminals *1* and *3* be reversed while the field terminals are left attached to *1* and *2*, the direction of rotation will be reversed.

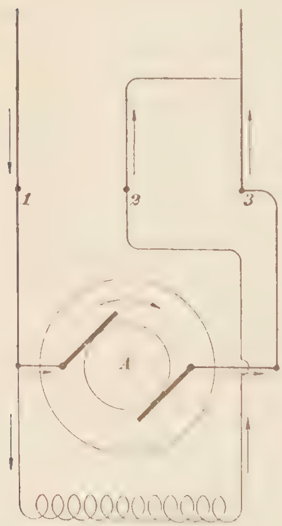


FIG. 23.

58. A series-wound motor will run in the same direction, no matter which of the supply lines is connected to its terminals *a*, *b*, Fig. 24. In fact, small series-wound motors may, if constructed properly and provided with laminated fields, be run on an alternating-current circuit. Reversing the line connections simply reverses the current through both armature and field, and does not, therefore, change the direction of rotation. In order to reverse the motor, either the armature terminals *c*, *d* must be interchanged, so as to reverse the current through the armature only, or the terminals *d*, *b* must be interchanged, so as to reverse the current through the field only. In street-railway work the motors are usually reversed by reversing the current through the armature, the current through the field remaining unaltered. These changes are made by means of the reversing switch placed in the car controller. All motors that are reversed during their operation should be provided with radial carbon brushes.

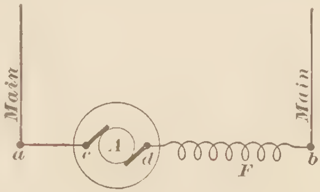


FIG. 24.

When it is desired to reverse a motor while it is running, it is very necessary to insert a resistance in the armature circuit before reversing the current through the armature. It must be remembered that the counter E. M. F. that the motor was generating just before reversal becomes an active E. M. F. and helps to make the current flow through the armature as soon as the current is reversed, and this action continues until the motor starts to turn in the opposite direction. If, for example, a 110-volt motor were reversed while running, without inserting any resistance, the effect would be the same as if the motor armature were connected directly across 220-volt mains, because the whole E. M. F. that the motor was previously generating would be effective in aiding the line E. M. F. It is best, therefore, when possible, to let the motor drop considerably in speed, or even come to a standstill, before reversing it, and where this cannot be done considerable resistance should be inserted.

59. Reversing Switch.—Fig. 25 shows the connections of one form of reversing switch. Two metal bars B and B_1 are pivoted at the points T and T_1; one is extended and supplied with a handle H, and the two bars are joined together by a link L of some insulating material, such as fiber. Three contact pieces a, b, and c are arranged on the base of the switch, so that the free ends of the bars B and B_1 may rest either on a and b, as shown by the full lines, or on b and c, as shown by the dotted lines. The line is connected to the terminals T and T_1 and the motor armature between a and b, or *vice versa*, a and c being connected together.

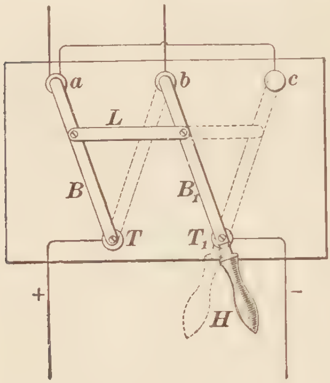


FIG. 25.

When the switch is in the position shown by the full lines, T is connected to a by the bar B, and T_1 to b by the bar B_1. If the switch is thrown by means of the handle H into the position indicated by the dotted lines, T is connected to b

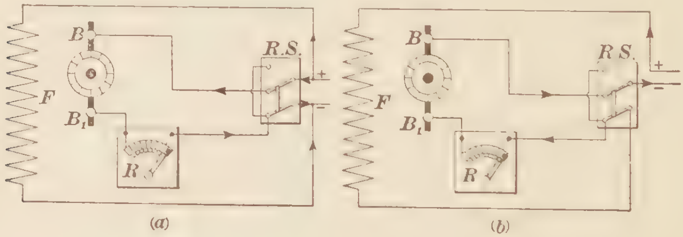


FIG. 26.

by the bar B, and T_1 to a by the bar B_1 and the connection between c and a. The direction of the current through the motor armature, or whatever circuit is connected between a and b, is thus reversed.

In order to reverse only the current in the armature, the reversing switch must be placed in the armature circuit

only. Fig. 26 (*a*) represents the connection for a reversing shunt motor and Fig. 26 (*b*) for a reversing series motor. The line terminals are marked + and – ; *R* is the starting resistance; *B* and B_1, the brushes of the motor; and *F*, the field coil of the motor. Some manufacturers combine the starting resistance and reversing switch in one piece of apparatus.

MULTIPOLAR ARMATURE WINDINGS.

60. Before leaving the subject of dynamos and motors we will take up briefly some of the more important points relating to the windings of armatures for multipolar direct-current machines. The two-pole type of machine has been replaced by the multipolar type in all but a few of the smaller sizes. Practically all the windings in use are of the drum type. This does not necessarily mean that the armature core is in the shape of a drum, because, in many modern machines, the armatures are so large in diameter compared with their length parallel to the shaft that the core takes the shape of a ring. In a drum armature, however, there is no wire passing through the center of the core and each turn represents two active conductors on the face of the armature. On the other hand, in a ring armature the turns are wound around the core instead of on the surface and each turn represents but one active face conductor. The distinction between a ring and drum winding is, therefore, more related to the way in which the winding is applied than to the actual shape of the core. Ring windings are still used on constant-current arc dynamos, but practically all other direct-current machines make use of drum windings, so that we will not consider ring windings here. It has been shown that an ordinary ring winding could be run in a multipolar field if as many brushes are provided as there are poles on the machine.

61. Application of Winding.—In the older styles of armatures the winding was applied by hand, the cotton

insulated wire being wound directly into the insulated slots. In nearly all modern machines the coils are wound on forms and taped to hold them in shape. They are then treated with insulating compound and baked, after which they are placed on the armature. Practically all modern drum armatures are of the toothed type, i. e., the coils are held in slots between projecting teeth on the surface of the core. Fig. 27 shows a few common styles of slot in use. The straight slot shown at (*a*) is one very largely used because the coils can be easily placed in it. With straight slots, it is, of course, necessary to use band wires to keep the coils from flying out. With the overhanging teeth (*b*) and (*c*) and the notched tooth (*d*) no band wires are necessary, the coils being held down in place by the strips *s*. It will be noticed that in all these slots the conductors are divided into two groups, an upper group *e* and a lower group *f*. Each side of a coil fills only half a slot instead of a whole slot. For example, in (*a*) the group *f* represents a side of one coil and *e* the side of another coil, each coil having eighteen turns of wire. Fig. 28 shows a typical formed coil as used on a multipolar armature. The sides *a a* and *b b* lie in the slots. The spread of the coil will, of course, be determined by the number of poles on the machine, because, when the group of conductors in side *a a* is under a north pole, group *b b* must be under a

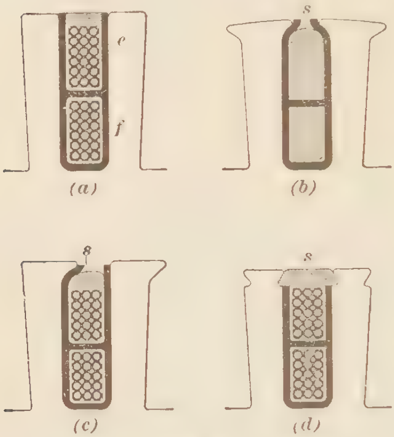


FIG. 27

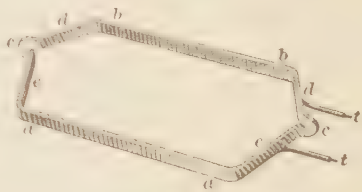


FIG. 28.

south pole. The portions *d e* project beyond the armature core and the two ends *t t* connect to the commutator.

The student will notice that the side *a a* lies in a lower plane than *b b*, the wires being given a turn at *c c* to accomplish this. Wires *a a* would, therefore, lie in the bottom part of a slot, as shown at *f*, Fig. 27 (*a*), and *b b* would lie in the top of a slot, as at *e*. The coils, therefore, lie in two layers, constituting what is sometimes called a **two-layer winding.** The object in arranging the coils in this way is to allow the end connections to pass each other easily and to lie compactly together. It also allows as many coils to be accommodated as there are slots, whereas if each side of a coil filled a whole slot, the number of coils would be only one-half the number of slots.

62. For armatures having a large current output, the winding is usually in the shape of copper bars of rectangular cross-section. Fig. 27 (*b*) shows a slot containing two bars. In some cases four or six bars per slot are used. Fig. 29 shows one element of a bar winding. The bars are bent as shown in Fig. 29 (*a*) and two of them are soldered together, as shown in (*b*), at the point *d*. The parts *a a* and *c c* lie in the slots and parts *b*, *b* form the cross-connections at the end. The part *b* on the front end serves both as the connection to the commutator and as the connection between the front ends of the bars, i. e., the ends of the bars next to the commutator.

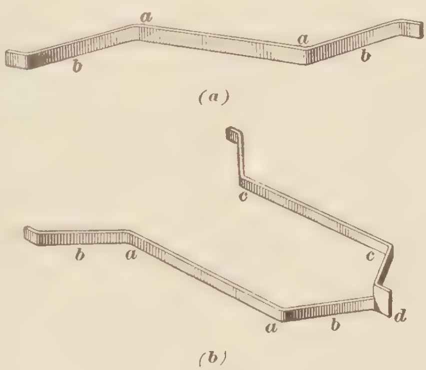


FIG. 29.

63. Types of Windings.—The number of different styles of winding that may be used on multipolar drum armatures is very large and it is possible to take up here

only a few points regarding the most common arrangements. A complete discussion of these windings belongs to the subject of dynamo design and is beyond the scope of this Course. For convenience, we may divide multipolar drum windings into two classes, *parallel windings* and *series windings*. The significance of these terms will be seen when the two styles are explained.

64. Elementary Principles.—Suppose that we have an armature core *A*, Fig. 30, that is placed in a six-pole field, the poles, of course, being alternately north and south around the armature. In order to illustrate the points to be brought out, we will show only one conductor lying in each slot and draw in only two conductors under each pole in order that

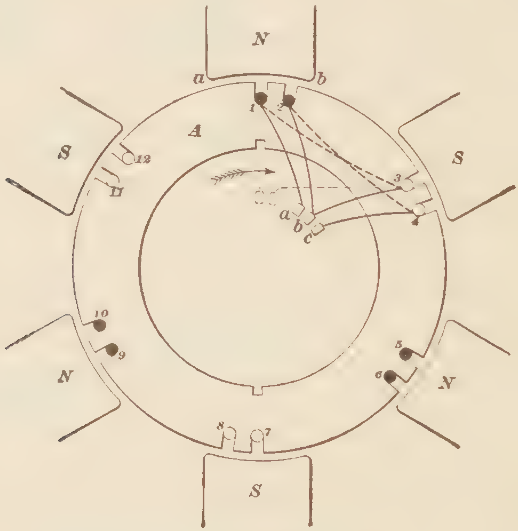


FIG. 30.

the drawing may be as simple as possible. For the present we will suppose that the conductors *1*, *2*, etc. are simply straight bars lying in the slots with their ends unconnected. Now when the armature revolves, E. M. F.'s will be induced in these conductors, and the E. M. F.'s in all the conductors passing under an *N* pole will be in one direction and those in

the conductors passing under an S pole will be in the opposite direction. We will assume that the E. M. F.'s in the conductors under the N poles are directed down through the paper and are shown black, while those in the conductors under the S poles are directed up through the paper and are shown light. The actual direction will, of course, depend on the direction of rotation of the armature, but this is not essential for the present purpose.

65. Now the problem in any direct-current drum winding is to connect these various conductors together and also to the commutator so that these various E. M. F.'s will add up or assist instead of oppose each other. The winding must also connect up into a closed circuit. It is evident then that we must connect the back end of an N conductor to the back end of an S conductor, as in Fig. 31 (a), because the conductors will then be in series and the E. M. F.'s will aid each other, as shown by the arrowheads. If two N conductors were connected across the back, as shown in Fig. 31 (b), the E. M. F.'s would neutralize each other. In passing, it may be well to state that by the *back end* of an armature is meant the end away from the commutator, and the *front end* is the end next to the commutator.

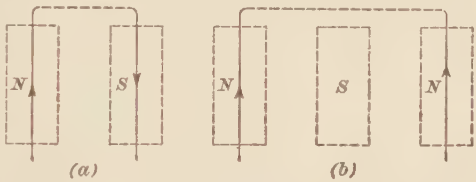


FIG. 31.

66. From the foregoing we see that the space spanned by the coils or bars, in connecting up an armature, must be about equal to the distance between the centers of the poles. This span is known as the **pitch**, and in a slotted armature the pitch must be about equal to the number of slots divided by the number of poles. A slot or two either way will make little or no difference as far as the operation of the machine is concerned, provided all other connections are correct; but the space spanned over by the coil should never be less than the span of the pole $a\ b$, Fig. 30.

67. In connecting together the front ends of the conductors, there are two methods that may be followed—one method results in a *parallel*, *multiple*, or *lap winding*, and the other in a *series* or *wave* winding. The *multiple* or *lap* method is shown in Fig. 30. Here the front end of conductor *1* is connected to commutator bar *a* and the back end of *1* is connected to the back end of *3* under the next *S* pole, as shown by the dotted line. The front end of *3* connects to the next commutator bar *b*. In other words, one end of a coil connects to a bar and the other end of the same coil connects to the *next* bar. The front end of *2* also connects to bar *b* and the back end of *2* connects to the back end of *4*, the front end of *4* connecting to the third bar *c*. This process of connecting is continued until all the coils are connected, the last end of the last coil connecting to bar *a*, thus making the winding form a closed circuit. In Fig. 30 the student will notice that each element of the winding laps back over the preceding one, hence the name **lap winding.**

68. Fig. 32 shows the method of making the front connections that gives rise to a **series** or **wave** winding. Starting from bar *a* we pass down bar *1*, across the back and up *3*, the same as in Fig. 30. Instead, however, of going back to the next bar, as in Fig. 30, the end of *3* is carried forwards to a bar *d* one-third the way around the commutator and from there connects to the front end of bar *5*. The back end of *5* connects to the back end of *7* and the front end of *7* is again carried forwards to a bar *f* one-third the circumference of the commutator in advance of *d*. *f* connects to *9* and *9* to *11*, as indicated, and *11* connects to bar *b*, which is next to *a*, the point from which we started. From *b* the winding again progresses around the armature in a similar manner and comes back to *c* and so on until the winding is completed and the last terminal of the last coil is connected to *a*.

Now the back connections for Fig. 32 are the same as the back connections for Fig. 30, but the front connections are

entirely different. In Fig. 30 the winding laps back on itself, while in Fig. 32 it progresses around the armature in zigzag style, thus giving rise to the term **wave winding.** Also note that in Fig. 30 there are only two conductors in series between the two commutator bars *a*, *b*, because the front end of conductor *3* connects to commutator bar *b*. On the other hand, in Fig. 32 there are six conductors (as many conductors or groups of conductors as there are poles) connected in series between *a* and *b*. These two figures

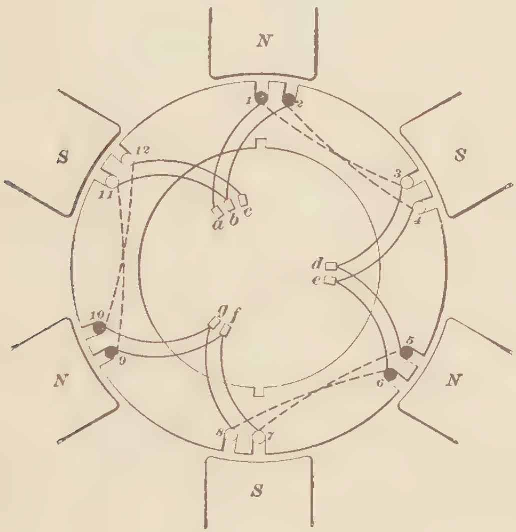


FIG. 32.

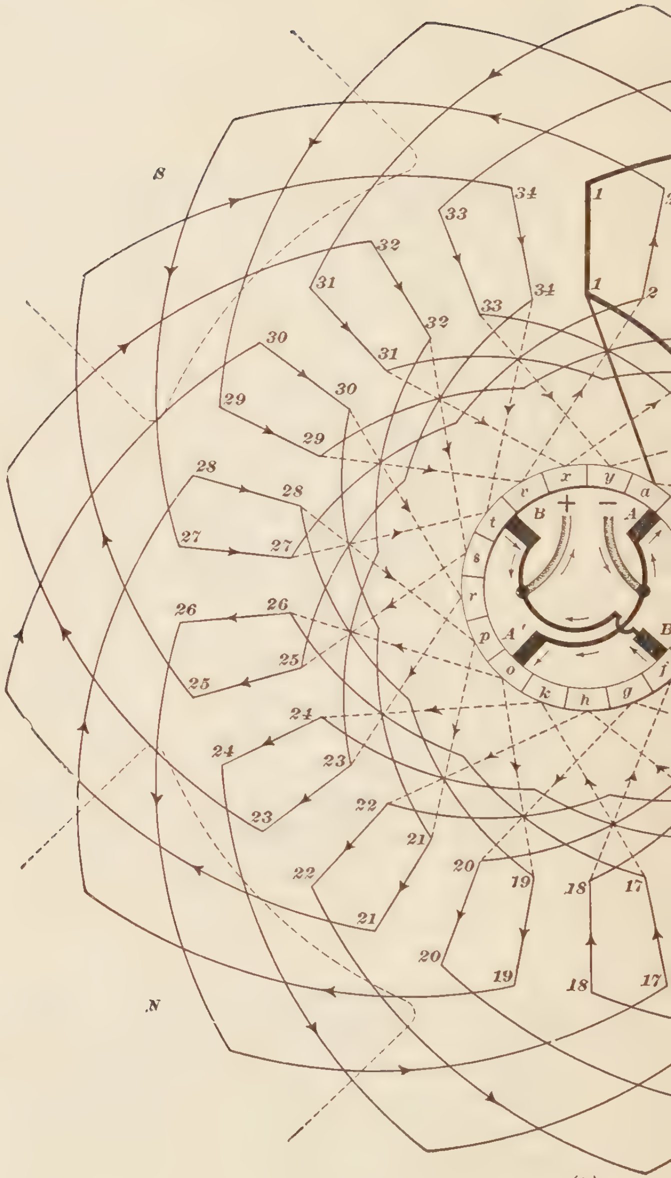
are intended principally to bring out the difference in the end connections of the two styles of winding. The other features will be brought out later in connection with more complete diagrams. In actual windings connected as above, conductor *1* would lie in the bottom of the slot and *3* in the top of the slot and there would be two layers of conductors on the armature. For the sake of simplicity, however, only one conductor is indicated in each slot and these are shown as lying in the bottom of the slots. If a *single layer winding*

were to be used, the connection from bar *b* would be taken to the next slot beyond *2* instead of *2*, as explained later (Art. **72**), in connection with a complete diagram for a single layer winding.

69. Arrangement of Commutator Connections.—It will be noticed in Figs. 30 and 32 that the ends of the conductors are not connected to the commutator bar directly in front of them. The connections are brought around through an angle of about one-twelfth a circumference, or given a **lead,** as it is usually termed. This is done in this case to make the connections symmetrical, though sometimes, as on railway motors, it is done to bring the brushes into a readily accessible position. For example, the winding in Fig. 30 would work just as well if the end connections were made as shown by the light dotted lines, though we would then have one short connection and one long one instead of two of more nearly equal length. If the connections were made as shown by the light dotted lines, the brushes would be placed about in line with the center of the space between the poles; if they were made as shown by the full lines, the brushes would come about in line with the centers of the poles. The effect is practically the same as if the commutator had been given a twist on the shaft after the connections were made, thus changing the relative position of the brushes and poles from that in which one would naturally expect to find them.

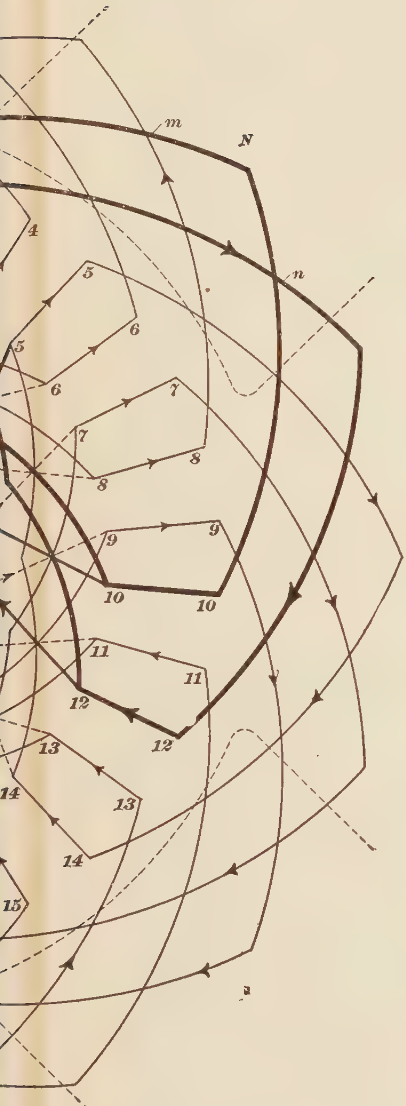
EXAMPLE OF PARALLEL-WOUND ARMATURE.

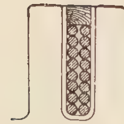
70. Fig. 33 (*a*) is a diagram illustrating the method of winding and connecting a parallel or lap-wound armature for a four-pole machine. Thirty-four slots are shown, though, of course, most armatures would have a larger number than this; this number, however, is sufficient to illustrate the method of winding. The sector-shaped figures, two of which are shown in heavy lines, represent the coils. The



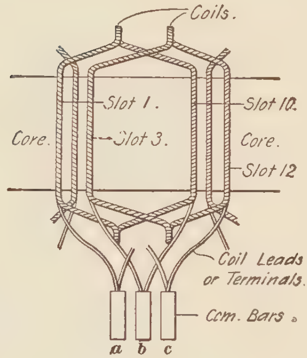
(a)

FIG. 33.

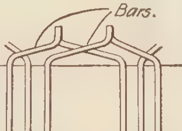




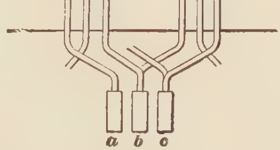
Cross Section of Slot.



(b)



Cross Section of Slot.



(c)

radial lines *1*, *1*, *2*, *2*, etc. represent the parts of the coils that lie in the slots and the outer curved lines represent the back ends of the coils. The inner curved lines represent the ends of the coils next to the commutator, and the brushes A, A', B, B' are shown inside the commutator in order that the diagram may not be complicated. The straight lines running from the coils to the commutator represent the coil leads, or terminals. In this figure only one bundle of conductors has been indicated for each slot because a two-layer winding would make the diagram more complicated. With the shape of coil shown in Fig. 33 (*b*) it would be awkward to make the crossings where the coils come out of the slots, and a single layer winding would seldom be used with coils having ends shaped like those shown. However, the figure shows the method more plainly than if a two-layer winding were illustrated, and for this reason only one bundle of conductors per slot is taken. There are seventeen coils, and, hence, seventeen commutator bars and the windings are arranged in the slot about as indicated in Fig. 33 (*b*).

The same diagram could also be taken to indicate a two-layer winding with seventeen slots only, by considering the even-numbered groups as the lower groups in the slots and the odd-numbered groups as the upper ones, as indicated in Fig. 34. For example, the group of conductors *1*, *1* or one side of coil *m* would be in the top of slot *1* and the other side *10*, *10* would be in the bottom of slot *5*. In what follows, however, we will consider that we have seventeen coils arranged in thirty-four slots, there being but one group of conductors in each slot.

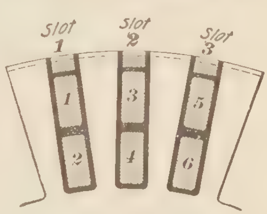


FIG. 34.

71. Connections.—The beginning of coil *1* is connected to bar *a*. The coils span about one-quarter of the armature and the other end of coil *m* is found at slot *10*. This end connects back to the next bar *b*. The beginning of the

coil *n* (coming out at slot *3*) connects to bar *b* and the end of *n* (coming out at slot *12*) connects to *c*, and so on with all the other coils, until finally the last wire coming out of slot *8* connects to *a*, thus making a closed winding. The student should start at bar *a* and trace out the connections all around the armature or, better still, draw a diagram for himself.

The brushes will be located in a position where they will connect with the conductor in the neutral space, hence one brush will be located at *A*. Suppose we assume that *A* is a negative brush and that current is flowing in at it. In the position shown the brush *A* bridges over between bars *a* and *b*, so that coil *m* is short-circuited and there will be no current in it except, perhaps, a local current. When the incoming current reaches *a* and *b* it divides, part flowing towards *8* and part towards *3*. Bear in mind that if the current flows from the front to the back in the conductors under the north poles, it must flow from back to front in those under the south poles. Wherever two opposing currents meet a brush must be placed, so that in tracing out the current if we come to such points we will know where brushes are necessary. First we will start at *b* and take the current that flows towards *3*. The path will be *b–3–3–12–12–c–5–5–14–14–d–7–7–16–16–e–9–9–18–18–f*. Now if we go on from *f* we encounter an arrow at *11* pointing against us because *11–11* is entering under a south pole, so that a brush must be placed at *f* in order that the opposing currents can unite and flow out. Now take the current flowing from *a* towards *8*. The path is *a–8–8–33–33–y–6–6–31–31–x–4–4–29–29–v–2–2–27–27–t*. If we go on from *t* we meet an arrow in the opposite direction because *34–34* is entering under a south pole, so that there must be another positive brush at *t* to allow the opposing currents to flow out. In the above two paths we have taken in only one-half the groups of conductors on the armature, so that if we used only these three brushes we would not utilize all the winding. If, however, we add another brush *A′* we open up two more paths for the current. These are *o–19–19–28–28–p–21–21–30–30–r–23–23–32–*

32–s–25–25–34–34 to brush *t* and out on the + armature lead. The other path from *A′* is *o–26–26–17–17–k–24–24–15–15–h–22–22–13–13–g–20–20–11–11–f* and out at *B′*. It is necessary, therefore, in a parallel or lap winding to have as many brushes or sets of brushes as there are poles—in this case four. Since brushes *B* and *B′*, *A* and *A′* are of the same polarity, they are connected together permanently by means of connecting rings. The brushes are rigidly mounted (for a four-pole machine) 90° or one-quarter a circumference apart, but the group of brushes as a whole can be shifted around the commutator in order to set them at the non-sparking point. In the armature shown in Fig. 33 (*a*) there are, then, four parallel paths for the main current, as indicated diagrammatically in Fig. 35, and for this reason the winding is called a **parallel,** or **multiple,** as well as a lap winding. If the machine had six poles, there would be six sets of brushes 60° apart instead of four sets 90° apart, and there would be six paths for the main current, and so on for any number of poles.

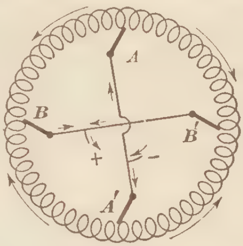


FIG. 35.

Fig. 33 (*b*) and (*c*) shows more nearly how the connections would be arranged; (*b*) shows the arrangement for a coil winding and (*c*) for a bar winding, there being but one bar in each slot.

72. Winding Requirements.—In Fig. 33 (*a*) the student will notice that one side of a coil is in an odd-numbered winding space and the other side in an even-numbered space; for example, coil *m* lies in slots *1* and *10*, and the number of slots spanned over is $10 - 1 = 9$. This number of slots or winding spaces spanned over is called the *pitch*. The number passed over in connecting the back ends of the conductors is called the *back pitch*, and the number passed over in connecting the front ends is called the *front pitch*. Also, in Fig. 33 (*a*) we wind from *1* to *10*, then from *3* to *12*, and so on. The even-numbered slots, *2*, *4*, *6*, etc., must be left

empty for the other sides of coils wound into *27*, *29*, *31*, etc. In coming across the front of the armature, *10* is connected to *3* by way of bar *b*, so that the front pitch is 7. In windings of this kind it is a general rule that the back pitch and the front pitch are both odd numbers and differ by 2. It must be remembered that the pitch is the number of winding spaces passed over. This may or may not be the same as the number of slots passed over, because we might have more than one winding space per slot, as shown in Fig. 27. Of course, it is evident, also, that the total number of conductors, or groups of conductors, must be divisible by the number of slots, or else there would be either an empty slot or two, or an extra coil or side of a coil with no place in which to put it.

73. Summary.—In regard then to simple parallel-wound armatures, such as are shown in Fig. 33 (*a*), we may sum up the following:

A parallel-wound drum armature must be provided with as many sets of brushes as there are poles on the machine.

There are as many paths for the current through the armature as there are poles on the machine, so that the current that flows in the armature conductor is equal to the total current delivered divided by the number of poles.

The front pitches and back pitches must both be odd numbers and differ by 2.

The total number of conductors, or groups of conductors, must be divisible by the number of slots.

Parallel-wound armatures are widely used and are especially adapted for machines that have to deliver heavy currents, because the current in the armature is subdivided and the size of the armature wire is kept down. On the other hand, they are not so well adapted for the generation of high pressures, because the voltage generated depends on the number of conductors connected in series between the brushes, and with this winding the number connected in series is only the total number divided by the number of poles.

EXAMPLE OF SERIES-WOUND ARMATURE.

74. Connections.—Fig. 36 (*a*), (*b*), and (*c*) shows the same armature as in Fig. 33, provided with a series or wave winding instead of a multiple winding. The number of slots and arrangement of coils is the same as in Fig. 33, but the student must not assume that all armatures that are connected in multiple can also be connected in series, because such is not the case, as will be shown later. In Fig. 36 (*a*), the terminals from the coils have been given a backward lead of one-eighth a circumference, so that the brushes instead of falling between the pole pieces come opposite the centers of the poles, as in Fig. 33 (*a*). Starting from bar *a*, it is easily seen that the scheme of connection is the same as that already explained in connection with Fig. 32. The ends of coil *m* are connected to bars about one-half a circumference apart, i. e., bars *a* and *o*, instead of being connected to adjacent segments. Except for the method of making the connections to the commutator, the two armatures might look almost exactly alike, in fact, it is very often difficult to tell by a mere inspection whether an armature is provided with a series or a multiple winding. If, however, the terminals of a coil branch off, one to one side of the commutator and the other to the other side after leaving the slots, instead of both slanting in the same general direction, or towards the same side, as in Fig. 33 (*a*), it is usually safe to assume that the armature is series-wound.

75. We will place a brush *A* at a point opposite the center of one pole and assume that the current flows in at this brush and will mark the arrowheads as in Fig. 33 (*a*). Starting from bar *a* we have two paths, one of which is as follows: *a–1–1–10–10–o–19–19–28–28–b–3–3–12–12–p–21–21–30–30–c–5–5–14–14–r–23–23–32–32–d–7–7–16–16–s–25–25–34–34–e–9–9–18–18–t–27–27–2–2–f*. If we go farther than this, we encounter arrowheads in the opposite direction, so that there must be a brush at *f*. As a matter of fact, the brushes *A* and *B* are 90° apart, and bars *e* and *f* are bridged over so that the circuit *9–9–18–18–t–27–27–2–2–f* is short-circuited,

and these conductors have been left without arrowheads because no current flows in them, except, perhaps, a local current. The second path starting from *a* is *a–26–26–17–17–k–8–8–33–33–y–24–24–15–15–h–6–6–31–31–x–22–22–13–13–g–4–4–29–29–v–20–20–11–11–f* to the other brush *B*.

Now if the student will examine the above two paths he will notice that every group of conductors is accounted for and that the two brushes *A* and *B* are all that are necessary for the utilization of the whole winding. Although the machine has four poles, there are but two paths through the armature and but two sets of brushes are required. This is a decided advantage in some cases, especially on railway motors, where the two under brushes would be awkward to get at. The number of conductors connected in series between the brushes is one-half the total number on the armature, so that this winding is well adapted for the generation of fairly high pressures. It is a style of winding used very largely for 500-volt railway motors and generators. Fig. 36 (*b*) and (*c*) show the connections more nearly as arranged on the actual armature, (*b*) showing the coil arrangement and (*c*) the bar winding. In both these views the armature-core surface is supposed to be straightened out flat. It may be mentioned in passing that series windings are often called **two-circuit** windings because there are but two circuits through them from brush to brush no matter how many poles the machine may have.

76. Use of More Than Two Brushes.—Although, as pointed out above, two brushes are all that are necessary for the operation of a series-wound armature, more than two are frequently used. This is nearly always done on large generators and motors because two sets of brushes are not capable of handling the current properly unless the commutator is made very wide and expensive, so as to give sufficient contact surface. Two additional brushes *A'*, *B'* are, therefore, provided as shown by the dotted outlines in Fig. 36 (*a*). These are at right angles to the others (for a four-pole machine) and press on bars *o* and *t*. There is no

true neutral point at *o* and *t*, however, because no opposing currents meet at this point. The main current flowing in on the brush cable *C* divides, part of it entering at brush *A* and part of it at *A'*. The current flowing in at *A'* unites with that coming up to the bar *o* from *10*, *10* and flows on to *19*, *19*, as indicated by the arrowheads. The addition of brush *A'* simply relieves *A* of part of the current, but *A'* is not necessary for the operation of the machine because there is no neutral point at bar *o*. In a similar manner, the addition of brush *B'* relieves *B* of part of the outgoing current. Fig. 37 represents the winding diagrammatically. *1*, *2*, *3*, and *4* represent groups of conductors. Groups *2* and *3* are connected in series between brushes *A* and *B* and groups *1* and *4* are also connected in series and the two paths so formed are in parallel. Then we have between the two brushes *A* and *B* two parallel paths, each consisting of one-half the total number of conductors in series.

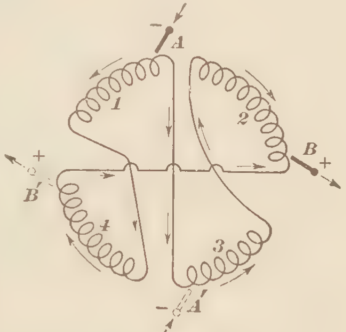


FIG. 37.

The path of the current from *A* to *B* is indicated by the arrows, and it is easily seen that additional brushes can be added at *A'* and *B'* or that the machine will work with *A* and *B* alone. This diagram is only intended to show the function of brushes *A'* and *B'* a little more clearly than Fig. 36, and the connections of the coils represent those of the armature in principle only. The actual connections would, of course, be as shown in Fig. 36.

77. Arrangement of Brushes for Six-Pole Machine. The foregoing has been given more particularly with reference to a four-pole winding, but the winding for any number of poles is similar. The use of the series winding gives but two paths through the armature from brush to brush, no matter how many poles there may be, whereas the parallel

winding gives rise to as many paths as there are poles. A six-pole machine *with a series winding* could be operated with two brushes 60° apart, as shown in Fig. 38 (*a*), or two additional brushes could be added and the machine operated with four brushes. If the machine had to deliver a large current, six brushes would be provided, as shown at

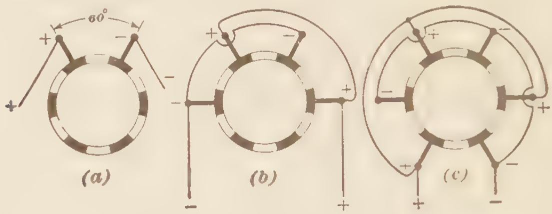


FIG. 38.

(*c*), and six brushes would have to be used in any event if the machine had a parallel-wound armature. When more than one pair of brushes is used, brushes of similar polarity are connected together by copper rings or cables mounted on the rocker that carries the brush holders, as indicated in (*b*) and (*c*).

Where a machine has a series-wound armature and is provided with more than two sets of brushes, the brush that makes the best contact with the commutator will take the most current. For example, in Fig. 36, if brush *A'* made a rather poor contact, brush *A* would take more than half the current and might spark badly. In the case of a parallel-wound armature, the points where the brushes rest are true neutral points and there is not the same danger of unequal distribution of current between the brushes.

78. Conditions for Winding.—When an armature is to be provided with a series winding, certain conditions must be fulfilled and certain relations must exist between the number of poles, the number of winding spaces, and the front and back pitches in order that the winding shall connect up properly and form a closed circuit. For a simple series winding, like that shown in Fig. 36, these relations are as follows:

Both the front and back pitches must be odd numbers. They may both be the same or may differ by 2.

The total number of winding spaces or slots (if there is but one conductor, or group of conductors, per slot) must be equal to the average pitch multiplied by the number of poles plus or minus 2.

Or, $$S = p\,y \pm 2,$$

where S = number of winding spaces;
p = number of poles;
y = average pitch.

The total number of conductors, or groups of conductors, must be divisible by the number of conductors per slot.

The second condition will be understood by referring to Fig. 36. Here we connect across the back from conductor *1* to *10*, hence the back pitch is 9. Across the front we connect from *10* to *19*, hence the front pitch is also 9 and the *average* pitch is also 9 $\left(\frac{9+9}{2} = 9\right)$.

The number of poles is four.

Hence, $$S = 4 \times 9 \pm 2 = 38 \text{ or } 34.$$

Hence, with the above front or back pitches we can use 38 or 34 winding spaces and have the armature connect up all right. If we used a two-layer winding, thus utilizing two winding spaces per slot, we would have 17 or 19 slots.

79. Cross-Connected Commutators.—Sometimes the connections for a two-circuit or series winding are made by connecting opposite bars on a four-pole commutator or bars one-third a circumference apart on a six-pole commutator. These cross-connections on the commutator connect the armature coils in series and give rise to a two-path winding, thus allowing the machine to be run with two or more brushes. These cross-connections, however, complicate the construction, and though used considerably at one time are not now used to any great extent. The method of

connection shown in Fig. 36 is simpler and represents in principle the one most commonly used for series windings.

80. Since a two-circuit winding provides only two paths for the current, it is evident that the current in the armature conductor will be one-half the total current supplied by the armature. The armature conductors would, therefore, be larger than would be called for if a parallel winding were used. On the other hand, there would not need to be as many conductors used to generate a given E. M. F., because one-half the total number of conductors on the armature are connected in series between the brushes. The output in watts that a given armature can deliver is, therefore, about the same no matter which style of winding is used.

81. The above will serve to bring out some of the main points connected with multipolar windings. As stated at the outset, there are a great many different styles of winding in use, but if the student understands the principles involved he should have little difficulty in following out any particular winding. The best way to do this is to draw diagrams similar to the figures already shown and trace out the path of the current.

GEOMETRICAL DRAWING

INSTRUMENTS AND MATERIALS

1. A **drawing** is a representation of objects on a plane surface by means of lines or lines and shades. When done by the use of free hand only, it is called **freehand drawing** or **sketching;** when instruments are used, so that greater exactness may be obtained, it is called **instrumental, or mechanical, drawing.**

2. All the instruments and materials required for the courses in drawing are mentioned in the following descriptions:

The **drawing board** should be made of well-seasoned, straight-grained pine, the grain running lengthwise. For this Course, the student will need a board of the following dimensions: length over all, $22\frac{1}{2}$ inches; width, $16\frac{1}{2}$ inches.

The drawing board illustrated in Fig. 1 is the one furnished in our students' drawing outfits and can be fully recommended as possessing the qualities a good and accurate board should have. It is made of several pieces of pine wood glued together to the required width of the board. A pair of hardwood cleats is screwed to the back of the board, the screws passing through the cleats in oblong slots with iron bushings, which allow the screws to move freely when drawn by the contraction and expansion of the board. Grooves are cut through half the thickness of the board over the entire back side. These grooves take the transverse resistance out of the wood and allow it to be controlled

by the cleats, at the same time leaving the longitudinal strength nearly unimpaired. In order to provide a perfectly smooth working edge for the head of the **T** square to slide against, a strip of hard wood is let into the short edges

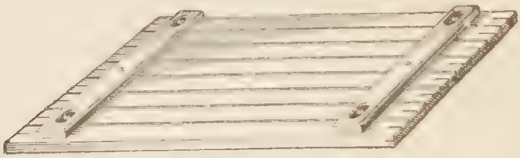


FIG. 1

of the board, and is sawed through in several places, in order to allow for the contraction and expansion of the board. The cleats also raise the board from the table, thus making it

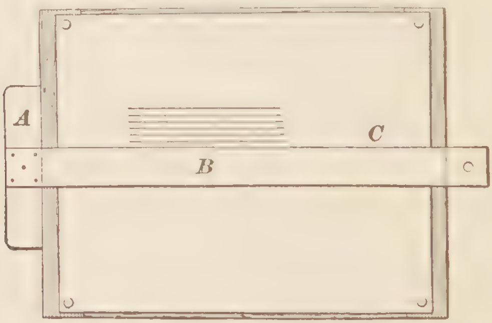


FIG. 2

easier to change the position of the board. When in use, the board is placed so that one of the short edges is at the left of the draftsman, as shown in Fig. 2.

3. The **T square** is used for drawing horizontal straight lines. The head *A* is placed against the left-hand edge of the board, as shown in Fig. 2. The upper edge *C* of the blade *B* is brought very near to the point through which it is desired to pass a line, so that the straight edge *C* of the blade may be used as a guide for the pen or pencil. It is evident that all lines drawn in this manner will be parallel.

Vertical lines are drawn by means of triangles. The triangles most generally used are shown in Figs. 3 and 4, each of which has one right angle. The triangle shown in Fig. 3

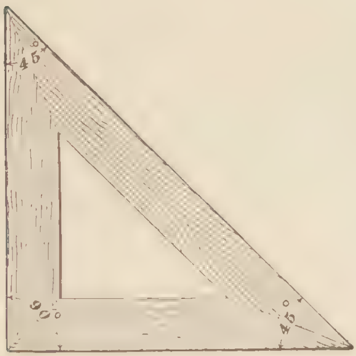


FIG. 3

FIG. 4

has two angles of 45° each, and that in Fig. 4 one of 60° and one of 30°. They are called *45°* and *60° triangles*, respectively.

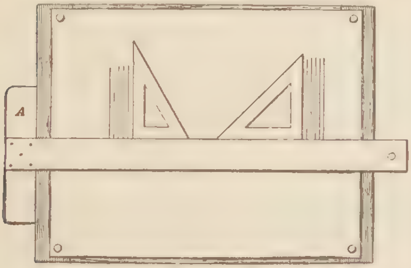


FIG. 5

To draw a vertical line, place the **T** square in position to draw a horizontal line, and lay the triangle against it, so as to form a right angle. Hold both **T** square and triangle lightly with the left hand, so as to keep them from slipping, and draw the line with the pen or pencil held in the right hand, and against the edge of the triangle. Fig. 5 shows the triangles and **T** square in position.

4. For drawing parallel lines that are neither vertical nor horizontal, the simplest and best way, when the lines are near together, is to place one edge of a triangle, as *a b*, Fig. 6, on the given line *c d*, and lay the other triangle, as *B*, against one of the two edges, holding it fast

with the left hand; then move the triangle *A* along the edge of *B*. The edge *a b* will be parallel to the line *c d*; and when the edge *a b* reaches the point *g*, through which it is desired to draw the parallel line, hold both triangles

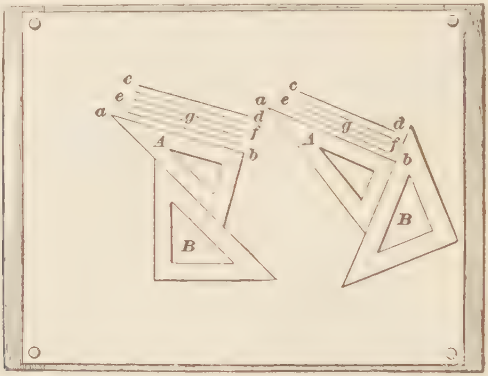


FIG. 6

stationary with the left hand and draw the line *e f* by passing the pencil along the edge *a b*. Should the triangle *A* extend too far beyond the edge of the triangle *B* after a number of lines have been drawn, hold *A* stationary with the left hand and shift *B* along the edge of *A* with the right hand and then proceed as before.

5. A line may be drawn at right angles to another line which is neither vertical nor horizontal, as illustrated in Fig. 7. Let *c d* be the given line (shown at the left-hand side). Place one of the shorter edges, as *a b*, of the triangle *B* so that it will coincide with the line *c d*; then, keeping the triangle in this position, place the triangle *A* so that its long edge will come against the long edge of *B*. Now, holding *A* securely in place with the left hand, slide *B* along the edge of *A* with the right hand, when the lines *h i*, *m n*, etc. may be drawn perpendicular to *c d* along the edge *b f* of the triangle *B*. The dotted lines show the position of the triangle *B* when moved along the edge of *A*.

6. The right-hand portion of Fig. 7 shows another method of accomplishing the same result, and illustrates

how the triangles may be used for drawing a rectangular figure, when the sides of the figure make an angle with the T square such that the latter cannot be used.

Let the side *c d* of the figure be given. Place the *long* side of the triangle *B* so as to coincide with the line *c d*, and bring the triangle *A* into position against the lower side of *B*, as shown. Now, holding the triangle *A* in place with the left hand, revolve *B* so that its other short edge will rest against the long edge of *A*, as shown in the dotted position at *B'*. The parallel lines *c e* and *d f* may now be drawn

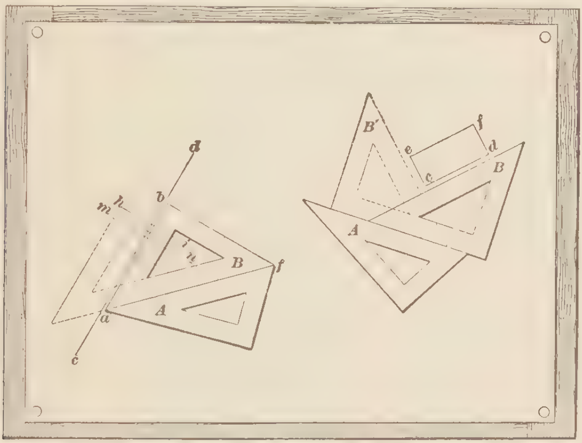


Fig. 7

through the points *c* and *d* by sliding the triangle *B* on the triangle *A*, as described in connection with Fig. 6. Measure off the required width of the figure on the line *c e*, reverse the triangle *B* again to its original position, still holding the triangle *A* in a fixed position with the left hand, and slide *B* upon *A* until the long edge of *B* passes through *e*. Draw the line *e f* through the point *e*, and *e f* will be parallel to *c d*. The student should practice with his triangles before beginning drawing.

7. The **compasses,** next to the T square and triangles, are used more than any other instrument. A pencil and pen point are provided, as shown in Fig. 8, either of which

may be inserted into a socket in one leg of the instrument, for the drawing of circles in pencil or ink. The other leg is fitted with a needle point, which acts as the center about which the circle is drawn. In all good instruments, the needle point itself is a separate piece of round steel wire, held in place in a socket provided at the end of the leg. The wire should have a square shoulder at its lower end, below which a fine, needle-like point projects. The *lengthening bar*, also shown in the figure, is used to extend the leg carrying the pen and pencil points when circles of large radii are to be drawn.

The joint at the top of the compasses should hold the legs firmly in any position, and at the same time should permit their being opened or closed with one hand. The joint may be tightened or loosened by means of a screwdriver or wrench, which accompanies the compasses.

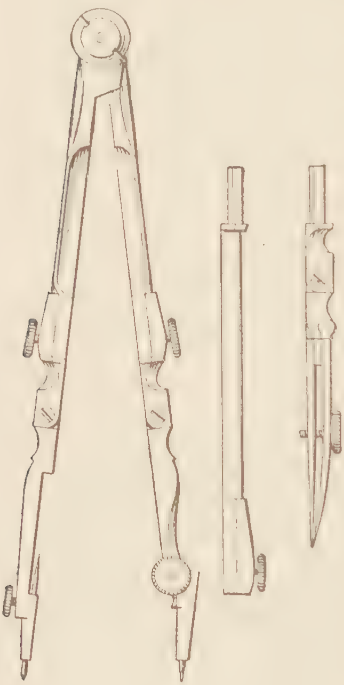


FIG. 8

It will be noticed in Fig. 8 that each leg of the compasses is jointed; this is done so that the compass points may always be kept perpendicular to the paper when drawing circles, as in Fig. 11.

The style of compasses shown in Fig. 8 have what is called a *tongue joint*, in which the head of one leg has a tongue, generally of steel, which moves between two lugs on the other leg. Another common style of joint is the *pivot joint*, in which the head of each leg is shaped like a disk and the two disks are held together in a fork-shaped brace either by means of two pivot screws or by one screw penetrating both disks.

The brace that forms a part of this joint is generally provided with a handle, as the shape of the joint makes it rather

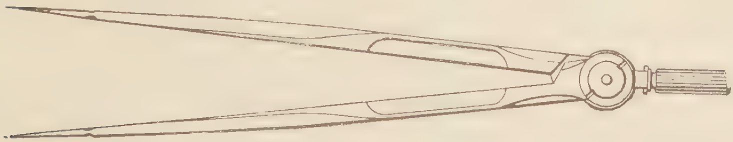


FIG. 9

awkward to hold the compasses by the head, as is usual with instruments provided with tongue joints. In Fig. 9 is shown a common style of pivot joint.

8. The following suggestions for handling the compasses should be carefully observed by those who are beginning the subject of mechanical drawing. Any draftsman who handles his instruments awkwardly will create a bad impression, no matter how good a workman he may be. The tendency of

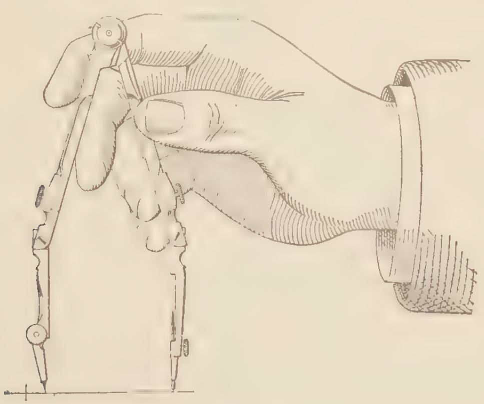


FIG. 10

all beginners is to use both hands for operating the compasses. This is to be avoided. The student should learn at the start to open and close them with one hand, holding them as shown in Fig. 10, with the needle-point leg resting between the thumb and fourth finger, and the other leg between the middle and forefinger. When drawing circles,

hold the compasses lightly at the top between the thumb and forefinger, or thumb, forefinger, and middle finger, as in Fig. 11. Another case where both hands should not be used is in locating the needle point at a point on the drawing about which the circle is to be drawn, unless the left hand is used merely to steady the needle point. Hold the compasses as shown in Fig. 10, and incline them until the under side of the

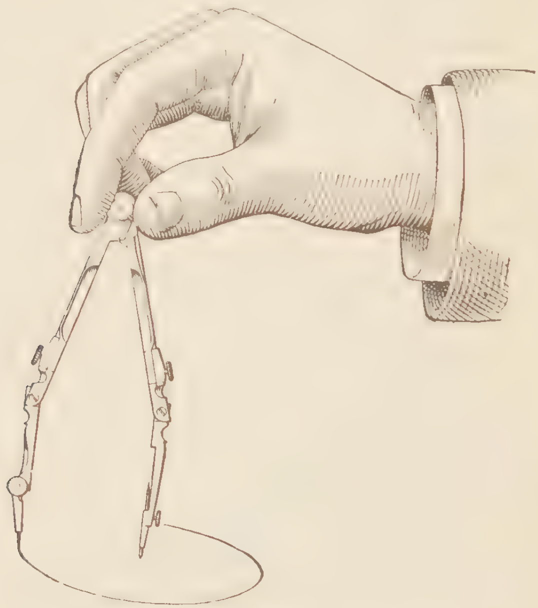


FIG. 11

hand rests upon the paper. This will steady the hand so that the needle point can be brought to exactly the right place on the drawing. Having placed the needle at the desired point, and with it still resting on the paper, the pen or pencil point may be moved out or in to any desired radius, as indicated in Fig. 10. When the lengthening bar is used, both hands must be employed.

9. The compasses must be handled in such a manner that the needle point will not dig large holes in the paper. Keep

the needle point adjusted so that it will be perpendicular to the paper, when drawing circles, and *do not bear upon it.* A slight pressure will be necessary on the pen or pencil point, *but not on the needle point.*

10. The **dividers,** shown in Figs. 9 and 12, are used for laying off distances upon a drawing, or for dividing straight lines or circles into parts. The points of the dividers should be *very* sharp, so that they will not punch holes in the paper larger than is absolutely necessary to be seen. Compasses are sometimes furnished with two steel divider points, besides the pen and pencil points, so that the instrument may be used either as compasses or dividers. This is the kind illustrated in Fig. 12. When using the

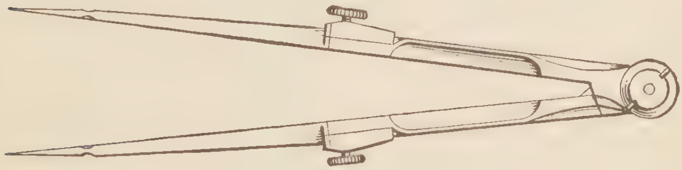


FIG. 12

dividers to space a line or circle into a number of equal parts, hold them at the top between the thumb and forefinger, as when using the compasses, and step off the spaces, turning the instrument alternately to the right and left. If the line or circle does not space exactly, vary the distance between the divider points and try again; so continue until it is spaced equally. When spacing in this manner, great care must be exercised not to press the divider points into the paper; for, if the points enter the paper, the spacing can never be accurately done. The student should satisfy himself of the truth of this statement by actual trial.

11. The **bow-pencil** and **bow-pen,** shown in Fig. 13, are convenient for describing small circles. The two points of the instruments must be adjusted to the same length; otherwise, very small circles cannot be drawn. To open or close either of these instruments, support it in a vertical

position by resting the needle point on the paper and bearing slightly on the top of it with the forefinger of one hand, and turn the adjusting nut with the thumb and middle finger of the same hand.

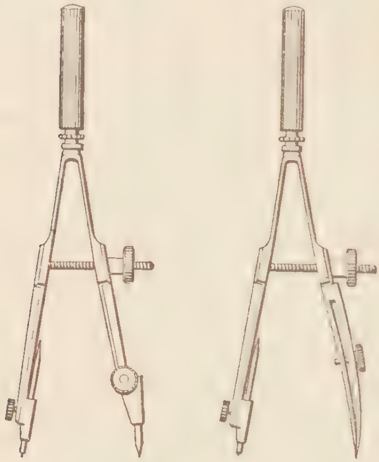


FIG. 13

12. Drawing Paper and Pencils.—The drawing paper recommended for this series of lessons is T. S. Co.'s cold-pressed demy, the size of which is 15″ × 20″. It takes ink well and withstands considerable erasing. The paper is secured to the drawing board by means of **thumbtacks.** Four are usually sufficient—one at each corner of the sheet (see Fig. 7). Place a piece of paper on the drawing board, and press a thumbtack through one of the corners about $\frac{1}{4}$ or $\frac{3}{8}$ of an inch from each edge. Place the T square in position for drawing a horizontal line, as before explained, and straighten the paper so that its upper edge will be parallel to the edge of the T-square blade. Pull the corner diagonally opposite that in which the thumbtack was placed, so as to stretch the paper slightly, and push in another thumbtack. Do the same with the remaining two corners. For drawing in pencil, an HHHH pencil of any reputable make should be used The pencil should be sharpened as shown at *A*, Fig. 14. Cut the wood away so as to leave about $\frac{1}{4}$ or $\frac{3}{8}$ of an inch of the lead projecting; then sharpen it flat by rubbing it against a fine file or a piece of

FIG. 14

fine emery cloth or sandpaper that has been fastened to a flat stick. Grind it to a sharp edge like a knife blade, and round the corners very slightly, as shown in the figure. If sharpened to a round point, as shown at B, the point will wear away very quickly and make broad lines; when so sharpened it is difficult to draw a line exactly through a point. The lead for the compasses should be sharpened in the same manner as the pencil, but should have its width narrower. *Be sure that the compass lead is so secured that when circles are struck in either direction, but one line will be drawn with the same radius and center.*

13. Inking.—For drawing ink lines other than arcs of circles, the **ruling pen** (or *right-line pen*, as it is sometimes called) is used. It should be held as nearly perpendicular to the board as possible, with the hand in the position

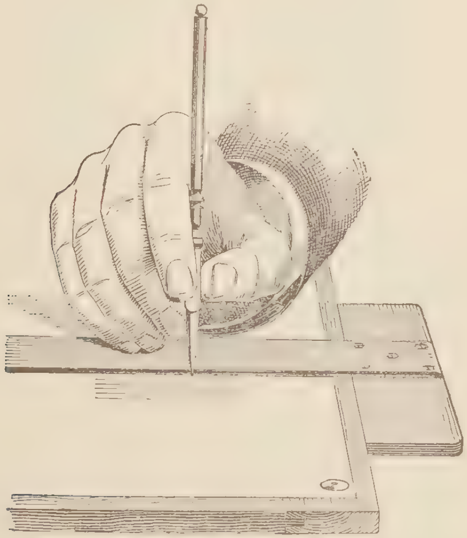


FIG. 15

shown in Figs. 15 and 16, bearing lightly against the **T** square or triangle, along the edge of which the line is drawn. After a little practice, this position will become natural, and no difficulty will be experienced.

14. The beginner will find that it is not always easy to make smooth lines. If the pen is held so that only one blade bears on the paper when drawing, the line will almost invariably be ragged on the edge where the blade does not bear. When held at right angles to the paper, as in Fig. 16, however, both blades will rest on the paper, and if the pen is in good condition, smooth lines will result. The pen must not be pressed against the edge of the T square or triangle, as the blades will then close together, making the line uneven. The edge should serve as a guide simply.

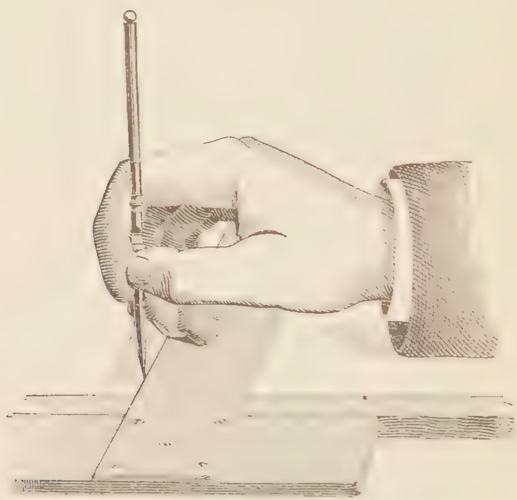


FIG. 16

In drawing circles with the compass pen, the same care should be taken to keep the blades perpendicular to the paper by means of the adjustment at the joint. In both the ruling pen and compass pen, the width of the lines can be altered by means of the screw which holds the blades together. The handles of most ruling pens can be unscrewed, and are provided with a needle point intended for use when copying maps by pricking through the original and the underlying paper, thus locating a series of points through which the outline may be drawn.

15. Drawing Ink.—The ink we recommend for the work in this Course is the T. S. Co.'s superior waterproof liquid India ink. A quill is attached to the cork of every bottle of this ink, by means of which the pen may be filled. Dip the quill into the ink and then pass the end of it between the blades of the drawing pen. Do not put too much ink in the pen, not more than enough to fill it for a quarter of an inch along the blades, otherwise the ink is liable to drop. Many draftsmen prefer to use stick India ink; and for some purposes this is to be preferred to the prepared liquid ink recommended above. In case the stick ink is bought, put enough water in a shallow dish (a common individual butter plate will do) to make enough ink for the drawing, then place one end of the stick in the water, and grind by giving the stick a circular motion. Do not bear hard upon the stick. Test the ink occasionally to see if it is black. Draw a fine line with the pen and hold the paper in a strong light. If it shows brown (or gray), grind a while longer, and test again. Keep grinding until a fine line shows *black*, which will usually take from fifteen minutes to half an hour, depending on the quantity of water used. The ink should always be kept well covered with a flat plate of some kind, to keep out the dust and prevent evaporation. The drawing pen may be filled by dipping an ordinary writing pen into the ink and drawing it through the blades, as previously described when using the quill. If liquid ink is used, all the lines on all the drawings will be of the same color, and no time will be lost in grinding. If stick ink is used, it is poor economy to buy a cheap stick. A small stick of the best quality, costing, say, a dollar, will last as long, perhaps, as five dollars' worth of liquid ink. The only reason for using liquid ink is that all lines are then sure to be of equal blackness and time is saved in grinding.

India ink will dry quickly on the drawing, which is desirable, but it also causes trouble by drying between the blades and refusing to flow, especially when drawing fine lines. *The only remedy is to wipe out the pen frequently* with a cloth. Do not lay the pen down for any great length of time when

it contains ink; wipe it out first. The ink may sometimes be started by moistening the end of the finger and touching it to the point, or by drawing a slip of paper between the ends of the blade. *Always keep the bottle corked.*

16. To Sharpen the Drawing Pen.—When the ruling, or compass, pen becomes badly worn, it must be sharpened. For this purpose a fine oilstone should be used. If an oilstone is to be purchased, a small, flat, close-grained stone should be obtained, those having a triangular section being preferable, as the narrow edge can be used on the inside of the blades in case the latter are not made to swing apart so as to permit the use of a thicker edge.

The first step in sharpening is to screw the blades together, and, holding the pen perpendicular to the oilstone, to draw it back and forth over the stone, changing the slope of the pen from downwards and to the right to downwards and to the left for each movement of the pen to the right and left. The object of this is to bring the blades to exactly the same length and shape, and to round them nicely at the point.

This process, of course, makes the edges even duller than before. To sharpen, separate the points by means of the screw, and rub one of the blades to and from the operator in a straight line, giving the pen a slight twisting motion at the same time, and holding it at an angle of about 15° with the face of the stone. Repeat the process for the other blade. To be in good condition, the edges should be fairly sharp and smooth, but not sharp enough to cut the paper. *All the sharpening must be done on the outside of the blades.* The inside of the blades should be rubbed on the stone only enough to remove any burr that may have been formed. Anything more than this will be likely to injure the pen. The whole operation must be done very carefully, bearing on lightly, as it is easy to spoil a pen in the process. Examine the points frequently, and keep at work until the pen will draw both *fine* lines and *smooth* heavy lines. Many draftsmen prefer to send the pens to be sharpened to the

dealer who sold them, and who is generally willing to do such sharpening at a trifling cost.

17. Irregular Curves.—Curves other than arcs of circles are drawn with the pencil or ruling pen by means of curved or irregular-shaped rulers, called **irregular curves** (see Fig. 17). A series of points is first determined through which the curved line is to pass. The line is then drawn through these points by using such parts of the irregular curve as will pass through several of the points at once, the curve being shifted from time to time as required.

Fig. 17

It is usually difficult to draw a smooth, continuous curve. The tendency is to make it curve out too much between the points, thus giving it a wavy appearance, or else to cause it to change its direction abruptly where the different lines join, making angles at these points. These defects may largely be avoided by always fitting the curve to at least three points, and, when moving it to a new position, by setting it so that it will coincide with part of the line already drawn. It will be found to be a great help if the line be first sketched in freehand, in pencil. It can then be penciled over neatly, or inked, without much difficulty, with the aid of the irregular curve, since the original pencil line will show the general direction in which the curve should be drawn. Whenever the given points are far apart, or fall in such positions that the irregular curve cannot always be made to pass through three of them, the line must invariably be sketched in at first.

As an example, let it be required to draw a curved line through the points a, b, c, d, etc., Fig. 18. As just stated, a part of the irregular curve must be used which will pass through at least three points. With the curve set in the first position A, its edge is found to coincide with four points

a, *b*, *c*, and *d*. The line may then be drawn from *a* around to *d*, or, better, to a point between *c* and *d*, since, by not continuing it quite to *d*, there is less liability of there being an angle where the next section joins on. For the next section of the line, the curve should be adjusted so as to coincide with a part of the section already drawn; that is, instead of adjusting it to points *d*, *e*, *f*, etc., it should be placed so as to

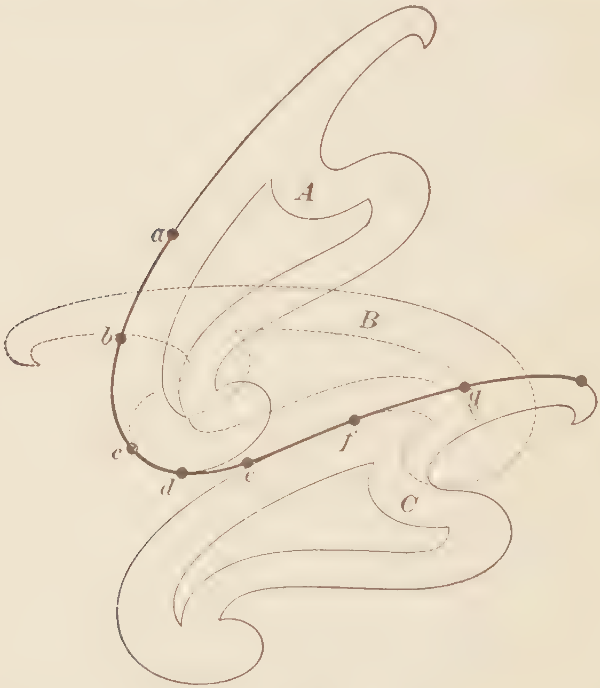


FIG. 18

pass through the point *c*, the part from *c* to *d* being coincident with the corresponding part of the first line drawn. The irregular curve is shown dotted in this position at *B*. Its edge passes through four points *c*, *d*, *e*, and *f*, and the line should be made to stop midway between the last two, as before.

Now, it will be noticed that the points *f* and *g* are so situated that the remainder of the line must curve up, instead of down, as heretofore, the change in curvature occurring at a

point between *e* and *f*. In this case, therefore, it is not necessary for the curve to extend back to *e*, through which point the line has already been drawn, but it may be placed in position *C* with its edge just tangent to the line at the point where the curvature changes.

It is to be noticed that in inking with the irregular curve, the blades of the pen must be kept tangent to its edge (i. e., the inside flat surface of the blades must have the same direction as the curve at the point where the pen touches the paper), which requires that the direction of the pen be continually changed.

18. The **scale** is used for obtaining measurements for drawings. The most convenient forms are the usual flat and triangular boxwood scales, having beveled edges, each of which is graduated for a distance of 12 inches. The beveled edges serve to bring the lines of division close to the paper when the scale is lying flat, so that the drawing may be accurately measured, or distances laid off correctly. The use of the graduations on scales will be explained when it is necessary to use the scale.

19. A **protractor** is shown in Fig. 19. The outer edge is a semicircle, with center at *O*, and is divided into

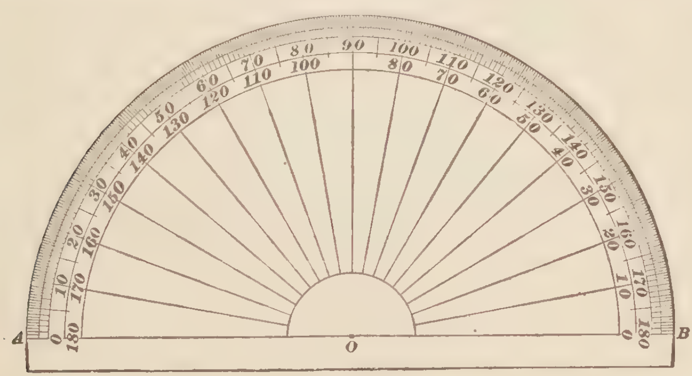


FIG. 19

360 parts. Each division is one-half of one degree, and, for convenience, the degrees are numbered from 0° to 180° from

both A and B. The protractor is used for laying off or measuring angles. Protractors are often made of metal, in which case the central part is cut away to make the drawing under it visible. When using the protractor, it must be placed so that the line OB, Fig. 19, will coincide with the line forming one side of the angle to be laid off or measured, and the center O must be at the vertex of the angle.

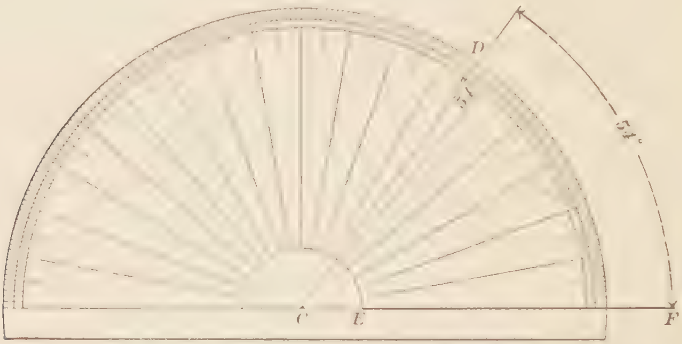


FIG. 20

For example, let it be required to draw a line through the point C, making an angle of 54° with the line EF, Fig. 20. Place the protractor upon the line EF, as just described, with the center O upon the point C. With a sharp-pointed pencil, make a mark on the paper at the 54° division, as indicated at D. A line drawn through C and D will then make an angle of 54° with EF. Greater exactness will be secured if the line EF be extended to the left, so that both zero marks (A and B, Fig. 19) can be placed on the line. This should always be done when possible.

LETTERING

20. In mechanical drawing, all headings, explanatory matter, and dimensions should be neatly printed on the drawing. Ordinary script writing is not permissible.

It is usually difficult for beginners to letter well, and unless the student is skilful at it, he should devote some time to practicing lettering before commencing the drawing. In correcting the plates, the lettering will be considered as well as the drawing. Many students think that it is only necessary to exercise special care when drawing the views on a plate, and that it is not necessary to take particular pains in lettering. This, however, is not the case, for, no matter how well the views may be drawn, if the lettering is poorly done, the finished drawing will not have a neat appearance. In fact, generally speaking, more time is required to make well-executed letters than to make well-executed drawings of objects. We earnestly request the student to practice lettering, and not to think that that part of the work is of no importance. The tudent should not be too hasty in doing the lettering. It takes an experienced draftsman considerable time to do good lettering, and no draftsman can perform this work as quickly as he can ordinary writing; therefore, no beginner should attempt to do what experienced draftsmen cannot do. In order to letter well, the work must be done slowly. Very frequently more time is spent in lettering a drawing than in inking in the objects represented. Instructions will be given in two styles of freehand lettering, both extensively used in American drafting rooms.

With the exception of the large headings or titles of the plates, the style and size of all lettering used on the original drawing plates of this Course are shown in Fig. 21. This

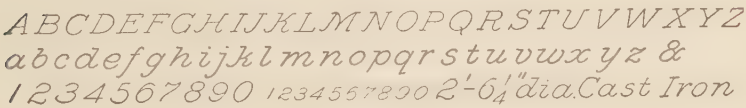


FIG. 21

style, although a little more elaborate and difficult in execution, was selected on account of its greater neatness and legibleness. The two styles are very similar in the formation of the letters, and although the student is advised to

select and use only one of the two on his drawings in this Course, he will find, after having mastered one of the styles, little difficulty in practicing the other.

When lettering, a Gillott's No. 303 pen should be used. The height of the capital letters should be $\frac{3}{32}''$, and of the small letters two-thirds of this, or $\frac{1}{16}''$. This applies to both styles of freehand lettering. *Do not make them larger than this.*

21. Before beginning to letter, horizontal guide lines should be drawn with the T square, to serve as a guide for the tops and bottoms of the letters (see Fig. 22). The outside lines should be $\frac{3}{32}''$ apart for the capitals, and the two lower lines $\frac{1}{16}''$ apart for the small letters.

FIG. 22

The letters should be made to extend fully up to the top, and down to the bottom, guide lines. They must not fall short of the guide lines, nor extend beyond them. Failure to observe this point will cause the lettering to look ragged, as in the second word in Fig. 22.

22. It is very important that all the letters have the same inclination. For example, by referring to Fig. 23 (*a*), it will be seen that the backs of letters like *B*, *E*, *l*, *g*, *d*, *i*, *t*, etc. are parallel and slant the same way.

FIG. 23 (*a*)

This is also true of both sides of letters like *H*, *M*, *n*, *u*, *h*, *y*, etc. To aid in keeping the slant uniform, draw parallel slanting lines across the guide lines with the 60° triangle, as in Fig. 23 (*b*), and, in lettering, make the backs or sides of the letters parallel with these lines.

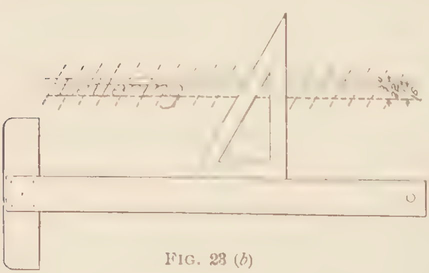


FIG. 23 (*b*)

23. A few points regarding the construction of the letters are illustrated in Fig. 24, in which the letters are shown upon an enlarged

scale. The capital letters *A*, *V*, *Y*, *M*, and *W* must be printed so that their general inclination will be the same as for the other letters. To print the *A*, draw the center line *a d*, having the common slant; from *a* draw the sides *a c* and *a b*, so that points *c* and *b* will each be $\frac{3}{64}''$ distant from point *d*. The side *a b* will be nearly perpendicular to the guide lines. The *V* is like an inverted *A*, and is drawn in the same way, the line *b d* being nearly perpendicular.

To make the *Y*, draw the center line *a d*, having the common slant, which gives the slant for the base of the letter. The upper part of the *Y* begins a little below its center, and is similar to the *V*, though somewhat narrower, as the letter should be only $\frac{5}{64}''$ wide at the top. Points *b* and *c* should be at equal distances from point *a*.

The two sides *b c* and *e f* of the *M* are parallel, and have the common slant. The *M* is made as broad as it is high, or $\frac{3}{32}''$. Having drawn the two sides, mark the point *d*, midway between the points *c* and *f*, and connect it with points *b* and *e*. The lines *b d* and *e d* should be slightly curved, as shown.

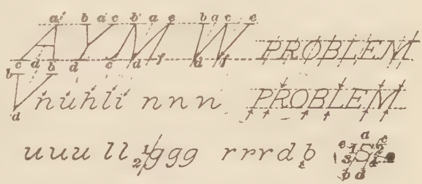


FIG. 24

In the *W* the two outside lines are not parallel, as in the *M*, but are farther apart at the top than at the bottom. Draw the line *a d*, having the common slant. Mark points *b* and *c*, which are exactly $\frac{1}{32}''$ from the point *a*. From *b* and *c*, draw lines *b d* and *c d*. The other half of the *W* is like the first part, *c f* being parallel to *b d* and *e f* parallel to *c d*. It will be seen that the *W* is composed of two narrow *V*'s, each $\frac{1}{16}''$ wide, the width of the whole letter being $\frac{1}{8}''$.

24. Capital letters like *P*, *R*, *B*, *L*, *E*, etc. should be printed so that their top and bottom lines will be *exactly horizontal.* This is illustrated in the two examples of the word *problem* in Fig. 24. In the first example, it will be noticed that the tops of the *P* and *R*, the bottom of the *L*,

and the tops and bottoms of the *B* and *E*, all run in the same direction as the guide lines, and coincide with them. In the second example, these lines are not horizontal, which makes the word look very uneven. It is also to be noticed that these lines extend beyond the upright lines in the first word, and that cross-lines are used on the bottom of the *P* and *R*, on the top of the *L*, and on the *M*. In the second word, these lines are omitted at the points indicated by the arrows. These features are found on most of the other capitals.

The small letters *n*, *u*, *h*, *l*, *i*, etc. should have sharp corners at the points indicated by the arrows in Fig. 24. They look much better that way, and are less difficult to make, than when they have round corners. Following these letters are five groups of letters containing *n*, *u*, *l*, *g*, and *r*. The first letter of each group is printed correctly, while the letters following show ways in which they should *not* be printed. In the case of the *g*, point *2* should fall in a slanting direction under point *1*, the slant being the same as *a d* of the preceding letters. The difference between *d* and *b* and the construction of the *s* are also shown in the same figure. The *b* should be made rounding at the point indicated. As a guide in making the *s*, draw the two lines *a b* and *c d*, having the common slant. The *s* should now be drawn so that it will touch these lines at points *1*, *3*, and *4*, but *not* at point *2*. It will be an additional help if the line *e x* is also drawn as a guide for the middle portion of the *s*; but care should be taken not to have it slant more than shown in the copy.

The letters *a*, *o*, *b*, *g*, etc. should be full and round; do not cramp them. It will be necessary to follow the copy closely until familiar with it. Notice that the figures are not made as in writing, particularly the *6*, *4*, *8*, and *9* (see Fig. 21). Try to space the letters evenly. Letter in pencil first, and, if not right, erase and try again.

25. Another style of freehand lettering is shown in Fig. 25. This style is extensively used for the lettering of

working drawings. It is more easily and rapidly made than the style previously described, and although not productive

ABCDEFGHIJKLMNOPQRSTUVWXYZ.

abcdefghijklmnopqrstuvwxyz &

12345678910 1234567890 2′-6¼″ dia. Cast Iron.

FIG. 25

of as high degree of neatness in appearance will be found very useful and acceptable for general office work.

A comparison between the two systems will disclose a great similarity in the detail formation of the letters.

26. The horizontal and slanting guide lines are drawn exactly in the same manner as for the style previously described, and if not followed, the results will be similar. See the uneven appearance of the second word in Fig. 26.

Horizontal Horizontal

FIG. 26

27. By studying the formation of the letters carefully, it will be found that many of them are formed on the same principle, as shown in Fig. 27.

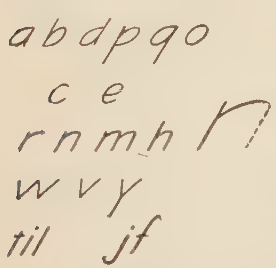


FIG. 27

The ovals of the letters *a*, *b*, *d*, *g*, *p*, and *q* are formed exactly alike and have a slant of 45° with the horizontal. These ovals should be made a little wider at the top than at the bottom. Care should be taken that the straight downward strokes are made parallel to the slanting guide lines. The letters *c* and *e* are commenced in the same way, but the upper loop in *e* should be formed in such a manner that its axis will be at an angle of 45° with the horizontal. The *r* is made by having the down stroke parallel to the slanting guide line

and the up stroke slightly curved in the same way as in the letter *n* (see Fig. 27). The strokes in the letters *j* and *f* are the same, with the position of the hook part reversed.

28. The capital letters shown in Fig. 28 are formed very nearly in the same manner as those shown in Art. **23,** but differ slightly by omitting the short spurs that give to the letters a more finished appearance.

In the capital *M*, however, there is a decided variation. The *M* is made with four strokes, putting in the parallel sides first. The two other strokes should join midway

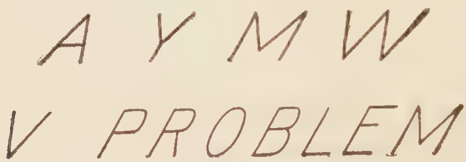


FIG. 28

between these sides and at a distance from the top of about $\frac{1}{3}$ of the height of the letter. These strokes, as will be seen, are straight and not curved.

29. The *numerals* should be $\frac{3}{32}''$ high and of the style shown in Fig. 25; fractions should be $\frac{1}{8}''$ high over all. In

FIG. 29

Fig. 29 the numerals are illustrated to a larger scale, and a comparison with the style shown in Fig. 21 will disclose several variations.

The loops of the *2*, *3*, *5*, *6*, and *9* should be formed so that their axes will be at an angle of 45° with the horizontal. It will be noted that the *7* differs widely from the style shown in Fig. 21, the down stroke not curving but having a straight slant of 45°. The axis of the *0* and the loops of the *8* should slant at an angle of 60°.

Diligent practice for a short time and careful observation of the forms of letters and numerals, as shown in Figs. 21–29, will soon enable the student to acquire skill and speed in this branch of drawing.

30. The alphabet shown in Fig. 30, called the **block letter,** is to be used for the large headings or titles of plates, as shown on the copy plates. This alphabet is *not* to be used on the first five geometrical drawing plates. The letters and figures are to be made $\frac{5}{16}''$ high and $\frac{1}{4}''$ wide, except *M*, which is $\frac{5}{16}''$ wide, and *W*, which is $\frac{3}{8}''$ wide. The thickness of all the lines forming the letters is $\frac{1}{16}''$, measured horizontally. The distance between any two letters of a word is $\frac{1}{16}''$, except where *A* follows *P* or *F*;

FIG. 30

where *V*, *W*, or *Y* follows *L*; where *J* follows *F*, *P*, *T*, *V*, *W*, or *Y*; where *T* and *A* are adjacent, or *A* and *V*, *W*, or *Y* are adjacent; in this case, the bottom extremity of *A* and the top extremity of *P*, *T*, *V*, *W* are in the same vertical line, etc.

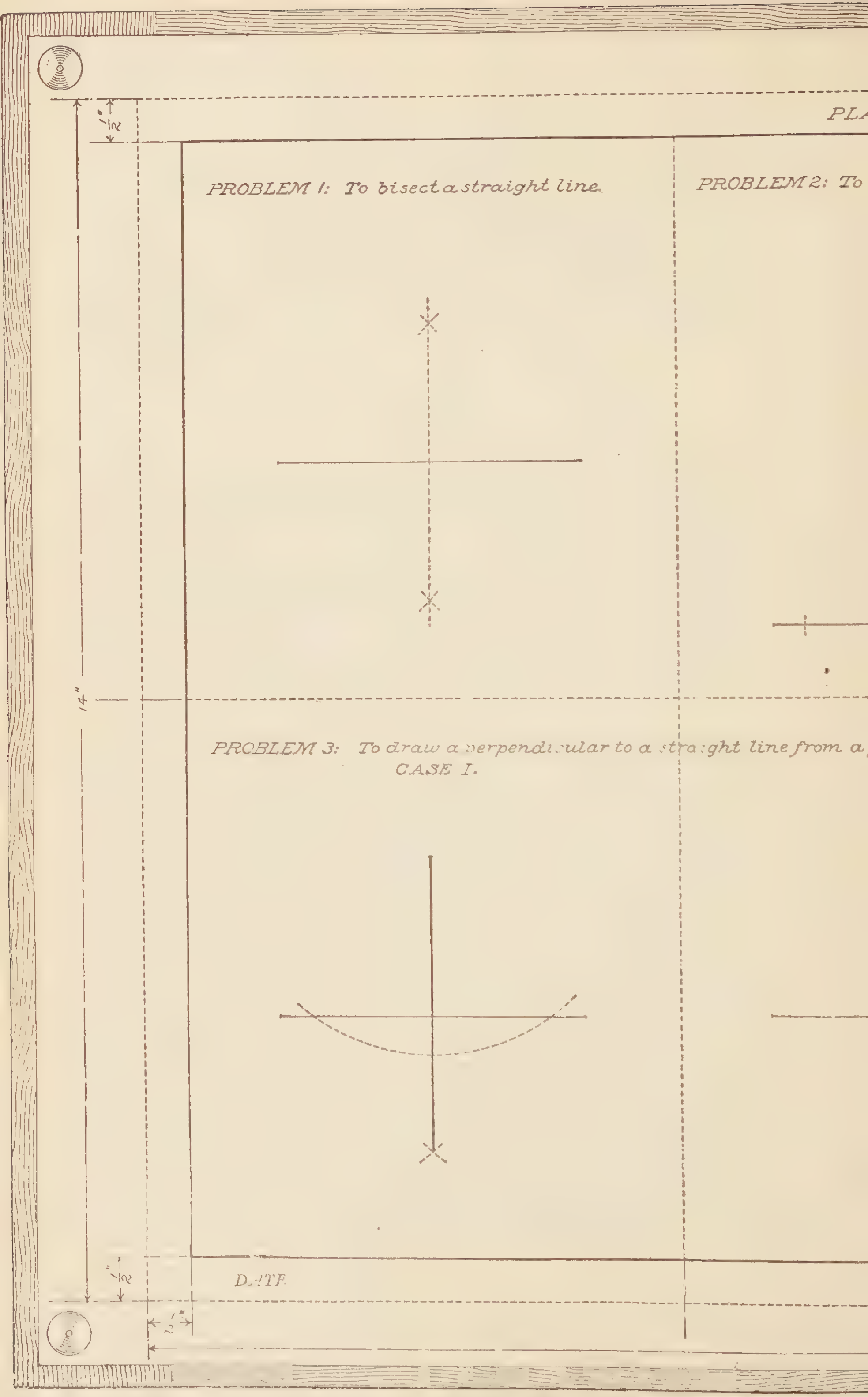
Since these letters are composed of straight lines, they can be made with the T square and triangle. In lettering the title of the drawing plates, the student should draw six horizontal lines $\frac{1}{16}''$ apart in lead pencil, to represent the thickness of the letters at the top, center, and bottom; then, by use of the triangle, he should draw in the width of

the letters and the spaces between them in lead pencil. Having the letters all laid out, he can very easily ink them in. Use the ruling pen for inking in the straight outlines of the letters, and the lettering pen for rounding the corners and filling in between the outlines. It is well to ink in all the perpendicular lines first, next the horizontal lines, and then the oblique lines.

PLATES

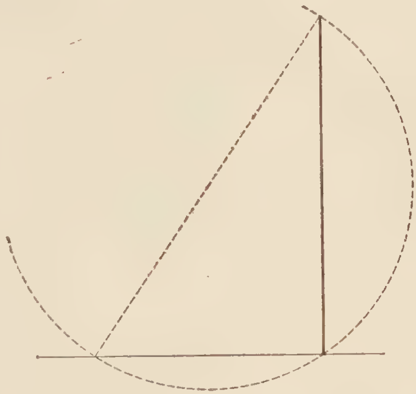
31. Preliminary Directions.—The size of each plate over all will be 14″ × 18″, having a border line ½″ from each edge all around, thus making the size of the space on which the drawing is to be made 13″ × 17″. The sheet itself must be larger than this when first placed upon the board, so that the thumbtack holes may be cut out; the extra margin is also very convenient for testing the pen, in order to see whether the ink is flowing well and whether the lines are of the proper thickness.

32. The first five plates will consist of practical geometrical problems which constantly arise in practice when making drawings. The method of solving every one of these problems should be carefully memorized, so that they can be instantly applied when the occasion requires, without being obliged to refer to the text for help. Particular attention should be paid to the lettering. Whenever any dimensions are specified, they should be laid off as accurately as possible. All drawings should be made as neat as possible, and the penciling entirely finished before inking in any part of it. Great care should be taken in distributing the different views, parts, details, etc. on the drawing, so that when the drawing is completed, one view will not be so near to another as to mar the appearance of the drawing. The hands should be perfectly clean, and should not touch the paper except when necessary. No lines should be erased except when *absolutely* necessary; for, whenever a line has once been erased, the dirt flying around in the air


PLA
PROBLEM 1: To bisect a straight line.
PROBLEM 2: To
PROBLEM 3: To draw a perpendicular to a straight line from a
CASE I.
DATE
1/2"
14"
1/2"
1/2"

…erpendicular to a straight line from a given point in that line.

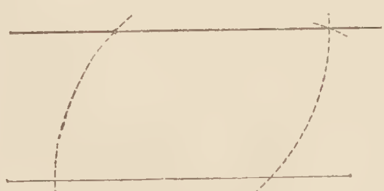
CASE II.



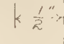
…hout it.

II.

PROBLEM 4: Through a given point to draw a straight line parallel to a given straight line.



NAME, CLASS LETTER AND NUMBER



and constantly falling on the drawing will stick to any spot where an erasure has been made, and it is then very difficult, if not impossible, to entirely remove it. For this reason, all construction lines that are to be removed, or that are liable to be changed, should be drawn lightly, that the finish of the paper may not be destroyed when erasing them. When it is found necessary to erase an ink blot or a line that has been inked in, only an *ink eraser* or *sand rubber* should be used. After the erasure has been made, the roughened part of the surface of the paper can be smoothed by rubbing with some hard, smooth substance, as a piece of ivory or the handle of a knife.

PLATE I

33. Take a sheet of drawing paper 15″ wide and 20″ long (demy size), and fasten it to the board as previously described. On this draw the outlines of the size of the plate, 14″ × 18″, and draw the border line all around $\frac{1}{2}$″ from the edge of the outline, leaving the space inside for the drawing 13″ × 17″. When the word *drawing* is used hereafter, it refers only to the space inside the border lines and the objects drawn upon it. To understand clearly what follows, refer to Plate I. Divide the drawing into two equal parts by means of a faint horizontal line. This line is shown dotted in Plate I, above referred to. Divide each of these halves into three equal parts, as shown by the dotted lines; this divides the drawing into six rectangular spaces. *These division lines are not to be inked in, but must be erased when the plate is completed.* On the first five plates, space for the lettering must be taken into account. For each of the six equal spaces, the lettering will take up one or two lines. The height of all capital letters on these plates will be $\frac{3}{32}$″, and of the small letters $\frac{2}{3}$ of this, or $\frac{1}{16}$″. The distance between any two lines of lettering will also be $\frac{3}{32}$″. The distance between the tops of the letters on the first line of lettering and the top line of the equal divisions of

the drawing is to be $\frac{1}{2}''$; and the space between the bottoms of the letters and the topmost point of the figure represented on the drawing within one of these six divisions must also be not less than $\frac{1}{2}''$. This makes a very neat arrangement, if the figure is so placed that the outermost points of the bounding lines are equally distant from the sides of one of the equal rectangular spaces. Consequently, if there is one line of lettering, no point of the figure drawn should come nearer than $\frac{1}{2}'' + \frac{3}{32}'' + \frac{1}{2}'' = 1\frac{3}{32}''$ to the top line of the space within which it is represented; or, if there are two lines of lettering, nearer than $\frac{1}{2}'' + \frac{3}{32}'' + \frac{3}{32}'' + \frac{3}{32}'' + \frac{1}{2}'' = 1\frac{9}{32}''$. The letter heading for each figure on the first five plates will be printed in heavy-faced type at the beginning of the directions explaining each problem. The student must judge for himself by the length of the heading whether it will take up one line or two, and make due allowance for the space it takes up. This is a necessary precaution, because the lettering should never be done until the rest of the drawing is entirely finished and inked in.

Problem 1.—**To bisect a straight line.**

See Fig. 31; also 1 of Plate I.

Construction.—Draw a straight line AB, $3\frac{1}{2}''$ long. With one extremity A as a center, and a radius greater than one-half of the length of the line, describe an arc of a circle on each side of the given line; with the other extremity B as a center, and the same radius, describe arcs intersecting the first two in the points C and D. Join C and D by the line CD, and the point P, where it intersects AB, will be the required point; that is, $AP = PB$, and P is the middle point

Fig. 31

of $A B$. Since $C D$ is perpendicular to $A B$, this construction also gives a *perpendicular to a straight line at its middle point.*

PROBLEM 2.—**To draw a perpendicular to a straight line from a given point in that line.**

NOTE.—As there are two cases of this problem, requiring two figures on the plate, the line of letters will be run clear across both figures, as shown in Plate I.

Case I.—*When the point is at or near the center of the line.* See Fig. 32; also 2, Case I, of Plate I.

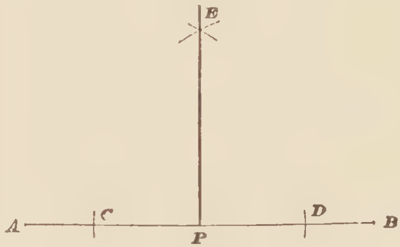


FIG. 32

CONSTRUCTION. — Draw $A B$ $3\frac{1}{2}''$ long. Let P be the given point. With P as a center, and any radius, as $P D$, describe two short arcs cutting $A B$ in the points C and D. With C and D as centers, and any convenient radius greater than $P D$, describe two arcs intersecting in E. Draw $P E$, and it will be perpendicular to $A B$ at the point P.

Case II.—*When the point is near the end of the line.* See Fig. 33; also 2, Case II, of Plate I.

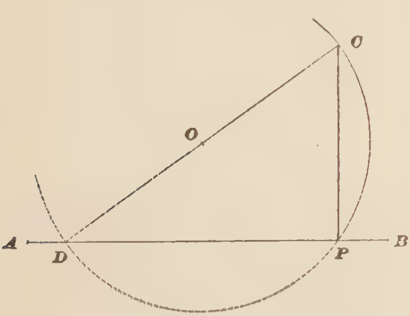


FIG. 33

Draw $A B$ $3\frac{1}{2}''$ long. Take the given point P about $\frac{3}{8}''$ from the end of the line. With any point O as a center, and a radius $O P$, describe an arc cutting $A B$ in P and D. Draw $D O$, and prolong it until it intersects the arc in the point C. A line drawn through C and P will be perpendicular to $A B$ at the point P.

PROBLEM 3.—**To draw a perpendicular to a straight line from a point without it.**

As in Problem 2, there are two cases.

Case I.—*When the point lies nearly over the center of the line.* See Fig. 34; also 3, Case I, of Plate I.

CONSTRUCTION.—Draw $A B$ $3\frac{1}{2}''$ long. Let P be the given point. With P as a center, and any radius $P D$ greater than the distance from P to $A B$, describe an arc cutting $A B$ in C and D. With C and D as centers, and any convenient radius, describe short arcs intersecting in E. A line drawn through P and E will be perpendicular to AB at F.

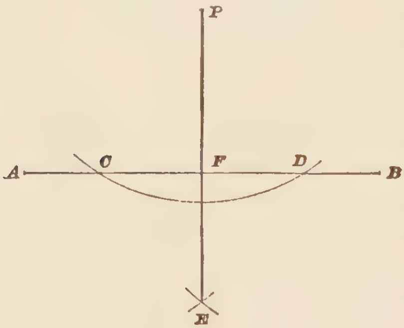


FIG. 34

Case II.—*When the point lies nearly over one end of the line.* See Fig. 35; also 3, Case II, of Plate I.

Draw $A B$ $3\frac{1}{2}''$ long, and let P be the given point. With any point C on the line $A B$ as a center, and the distance $C P$ as a radius, describe an arc $P E D$ cutting $A B$ in E. With E as a center, and the distance $E P$ as a radius, describe an arc cutting the arc $P E D$ in D. The line joining the points P and D will be perpendicular to $A B$.

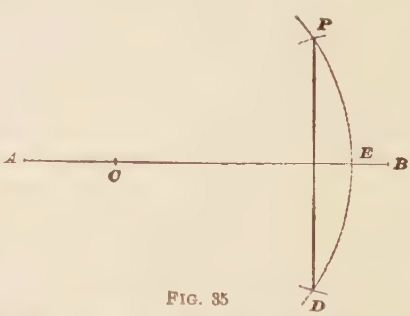


FIG. 35

PROBLEM 4.—**Through a given point, to draw a straight line parallel to a given straight line.**

See Fig. 36; also 4 of Plate I.

CONSTRUCTION.—Let P be the given point, and $A B$ the given straight line $3\frac{1}{2}''$ long. With P as a center, and any

convenient radius, describe an arc CD intersecting AB in D. With D as a center, and the same radius, describe the arc PE. With D as a center, and a radius equal to the chord of the arc PE, describe an arc intersecting CD in C. A straight line drawn through P and C will be parallel to AB.

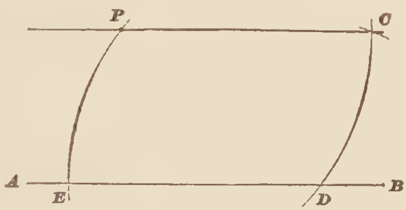


FIG. 36

34. These four problems form Plate I. They should be carefully and accurately drawn in with lead-pencil lines and then inked in. It will be noticed that on Plate I, and Figs. 31 to 36, the given lines are *light*, the required lines *heavy*, and the construction lines, which in a practical working drawing would be left out, are *light dotted.* This system must also be followed in the four plates which are to follow. A single glance enables one to see at once the reason for drawing the figure, and the eye is directed immediately to the required line.

In the first five plates, accuracy and neatness are the main things to be looked out for. The student should be certain that the lines are of *precisely* the length that is specified in the description. When drawing a line through two points, be sure that the line goes through the points; if it does not pass exactly through the points, erase it and draw it over again. If a line is supposed to end at some particular point, make it end there—do not let it extend beyond or fall short. Thus, in Fig. 36, if the line PC does not pass through the points P and C, it is not parallel to AB. By paying careful attention to these points, the student saves himself a great deal of trouble in the future. *Do not hurry your work.*

First ink in all of the light lines and light dotted lines (which have the same thickness); then ink in the heavy required lines after the pen has been readjusted. Now do the lettering (first read carefully the paragraphs under the head "Lettering"), and finally draw the heavy border lines,

which should be thicker than any other line on the drawing. The word "Plate" and its number should be printed at the top of the sheet, outside the border lines, and midway of its length, as shown. The student's name, followed by the words "Class" and "No.," and after this his Course letter and *class number* should be printed in the lower right-hand corner below the border line, as shown. Thus, John Smith, Class No. C 4529. The date on which the drawing was completed should be placed in the lower left-hand corner, below the border line. *All of this lettering is to be in capitals $\frac{3}{32}''$ high.* Erase the division lines, and clean the drawing by rubbing very gently with the eraser. Care must be exercised when doing this, or the inked lines will also be erased. It is best to use a so-called "Sponge Rubber" for this purpose, as it will not injure the inked lines. *If any part of a line has been erased or weakened, it must be redrawn.* Then write with the lead pencil your name and address in full on the back of your drawing, after which put your drawing in the empty tube which was sent you, and send it to the Schools.

HINTS FOR PLATE I

35. *Do not forget to make a distinction between the width of the given and required lines, nor forget to make the construction lines dotted.*

When drawing dotted lines, take pains to have the dots and spaces uniform in length. Make the dots about $\frac{1}{16}''$ long and the spaces only about one-third the length of the dots.

Try to get the work accurate. The constructions must be accurate, and all lines or figures should be drawn of the length or size previously stated. To this end, work carefully and keep the pencil leads very sharp, so that the lines will be fine.

The lettering on the first few plates, as well as on the succeeding plates, is fully as important as the drawing, and should be done in the neatest possible manner. Drawings sent in for correction with the lettering omitted will be returned for completion.

The reference letters like A, B, C, etc., as shown in Fig. 31, are not to be put on the plates.

Do not neglect to trim the plates to the required size. Do not punch large holes in the paper with the dividers or compasses. Remember that the division lines are to be erased—not inked in.

PLATE II

36. Draw the division lines in the same manner as described for Plate I. The following five problems (5 to 9, inclusive) are to be drawn in regular order, as was done in Plate I, with problems from 1 to 4. The letter headings are given in heavy-faced type after the problem number.

PROBLEM 5.—**To bisect a given angle.***

Case I.—*When the sides intersect within the limits of the drawing.* See Fig. 37.

CONSTRUCTION.—Let AOB be the angle to be bisected. Draw the sides OA and OB $3\frac{1}{2}''$ long. With the vertex O as a center, and any convenient radius, describe an arc DE intersecting OA at D and OB at E. With D and E as centers, and a radius greater than the chord of half the arc DE, describe two arcs intersecting at C. The line drawn through C and O will bisect the angle; that is, $AOC = COB$.

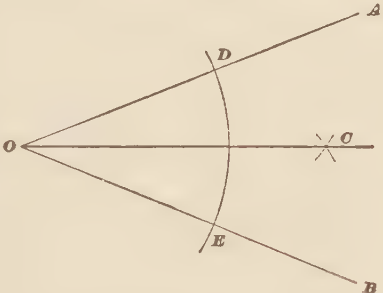


FIG. 37

Case II.—*When the sides do not intersect within the limits of the drawing.* See Fig. 38.

CONSTRUCTION.—Draw two lines, AB and CD, each $3\frac{1}{2}''$ long, and inclined towards each other as shown. With any

* Since the letter heading in this problem is very short, it will be better to place it over each of the two cases separately, instead of running it over the division line, as was done with the long headings of the two cases in Plate I. Put Case I and Case II under the heading, as in the previous plate.

point E on $C D$ as a center and any convenient radius, describe arc $F I G H$; with G as a center and same radius, describe arc $H L E F$, intersecting $F I G H$ in H and F. With L as a center and same radius, describe arc $K G J$; with I as

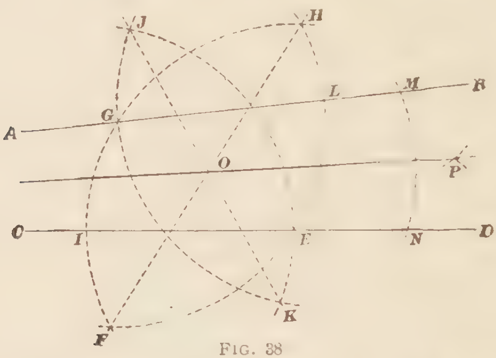


FIG. 38

a center and same radius, describe arc $J E K$, intersecting $K G J$ in K and J. Draw $H F$ and $J K$; they intersect at O, a point on the bisecting line. With O as a center and the same or any convenient radius, describe an arc intersecting $A B$ and $C D$ in M and N. With M and N as centers and any radius greater than one-half $M N$, describe arcs intersecting at P. A line drawn through O and P is the required bisecting line.

PROBLEM 6.—**To divide a given straight line into any required number of equal parts.**

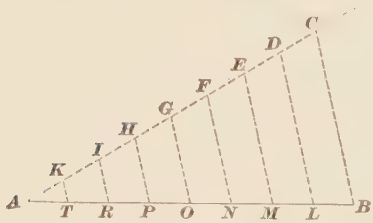


FIG. 39 (a)

See Fig. 39 (a).

CONSTRUCTION.—$A B$ is the given line $3\frac{7}{16}''$ long. It is required to divide it into eight equal parts. Through one extremity A of the line, draw an indefinite straight line $A C$, making any angle with $A B$. Set the dividers to any convenient distance, and space off eight equal divisions on $A C$, as $A K$, $K I$, $I H$, etc. Join C and B by the

straight line CB, and through the points D, E, F, G, etc. draw lines DL, EM, etc. parallel to CB, by using the two triangles; these parallels intersect AB in the points L, M, N, etc., which are equally distant apart. The spaces LM, MN, NO, etc. are each equal to $\frac{1}{8}AB$. Proceed in a similar way for any number of equal parts into which AB is to be divided.

Another method is shown in Fig. 39 (*b*). Draw AB as before, and erect the perpendicular BC. Now divide the length of AB by the number denoting the number of equal parts into which AB is to be divided, obtaining, in this case, $3\frac{7}{16}'' \div 8 = \frac{55}{128}''$. As AC is longer than AB, the equal divisions AK, KI, etc. are longer than AT, TR, etc. and may be made any convenient length greater than $AB \div 8$. In this case, $\frac{1}{2}''$ is the most convenient fraction nearest to and greater than $\frac{55}{128}''$; hence, consider AK, KI, etc. to be each $\frac{1}{2}''$ in length, thus making the length of AC $8 \times \frac{1}{2}'' = 4''$. With A as a center and a radius equal to $4''$, describe an arc cutting BC in C, and draw AC. Then with a scale lay off $AK = KI =$ etc. $= \frac{1}{2}''$, and project K, I, H, etc. upon AB, in T, R, P, etc., the required points. The advantage of this method over the other is that the **T** square and triangle can be used throughout, thus making it very much easier to draw the parallels DL, EM, etc.

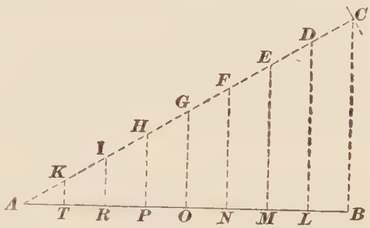


FIG. 39 (*b*)

The student, when drawing this plate, is at liberty to use either of the two methods given in this problem.

PROBLEM 7.—**To draw a straight line through any given point on a given straight line to make any required angle with that line.**

CONSTRUCTION.—In Fig. 40, AB is the given line $3\frac{1}{2}''$ long, P is the given point, and EOF is the given angle. With the vertex O as a center, and any convenient radius, describe

an arc EF cutting OE and OF in E and F. With P as a center, and the same radius, describe an arc CD. With D as a center, and a radius equal to the chord of the arc EF, describe an arc cutting CD in C. A line drawn through the points P and C will make an angle with AB equal to the angle O, or $CPD = EOF$.

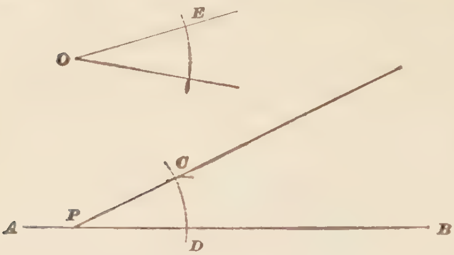


FIG. 40

PROBLEM 8.—**To draw an equilateral triangle, one side being given.**

CONSTRUCTION.—In Fig. 41, AB is the given side $2\frac{1}{2}''$ long. With AB as a radius, and A and B as centers, describe two arcs intersecting in C. Draw CA and CB, and CAB is an equilateral triangle.

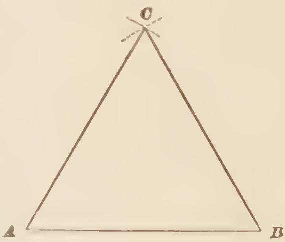


FIG. 41

PROBLEM 9.—**The altitude of an equilateral triangle being given, to draw the triangle.**

CONSTRUCTION.—In Fig. 42, AB is the altitude $2\frac{1}{4}''$ long. Through the extremities of AB draw the parallel lines CD and EF perpendicular to AB. With B as a center, and any convenient radius, describe the semicircle $CHKD$ intersecting CD in C and D. With C and D as centers, and the same radius, describe arcs cutting the semicircle in H and K. Draw BH and BK, and prolong them to meet EF in E and F. BEF is the required equilateral triangle.

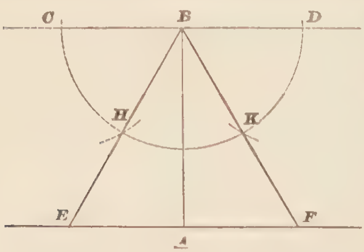


FIG. 42

This problem finishes Plate II. The directions for inking in, lettering, etc. are the same as for Plate I.

PLATE III

37. This plate is to be divided up like Plates I and II, and the six following problems are to be drawn in a similar manner:

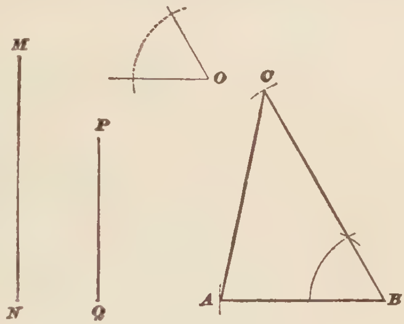


FIG. 43

PROBLEM 10.—**Two sides and the included angle of a triangle being given, to construct the triangle.**

CONSTRUCTION.—In Fig. 43, make the given sides MN $2\frac{1}{2}''$ long and PQ $1\frac{7}{8}''$ long. Let O be the given angle. Draw AB, and make it equal in length to PQ. Make the angle CBA equal to the given angle O, and make CB equal in length to the line MN. Draw CA, and CAB is the required triangle.

PROBLEM 11.—**To draw a parallelogram when the sides and one of the angles are given.**

CONSTRUCTION.—In Fig. 44, make the given sides MN $2\frac{1}{2}''$ long and PQ $1\frac{7}{8}''$ long. Let O be the given angle. Draw AB equal to MN, and draw BC, making an angle with AB equal to the given angle O. Make BC equal to PQ. With C as a center, and a radius equal to MN, describe an arc at D. With A as a center, and a radius equal to PQ, describe an arc intersecting the other arc in D. Draw AD and CD, and $ABCD$ is the required parallelogram.

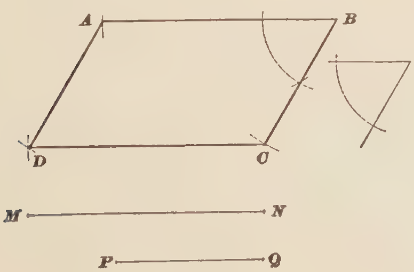


FIG. 44

PROBLEM 12.—**An arc and its radius being given, to find the center.**

CONSTRUCTION.—In Fig. 45, $A\ C\ D\ B$ is the arc, and $M\ N$, $1\frac{3}{4}''$ long, is the radius. With $M\ N$ as a radius, and any point C in the given arc as a center, describe an arc at O. With any other point D in the given arc as a center, and the same radius, describe an arc intersecting the first in O. O is the required center.

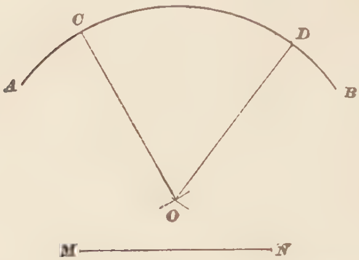


FIG. 45

PROBLEM 13.—**To pass a circumference through any three points not in the same straight line.**

CONSTRUCTION.—In Fig. 46, A, B, and C are the given points. With A and B as centers, and any convenient radius, describe arcs intersecting each other in K and I. With B and C as centers, and any convenient radius, describe arcs intersecting each other in D and E. Through I and K and through D and E, draw lines intersecting at O. With O as a center, and $O\ A$ as a radius, describe a circle; it will pass through A, B, and C.

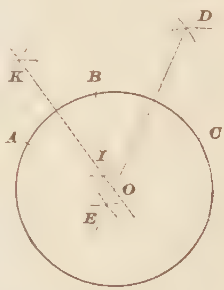


FIG. 46

PROBLEM 14.—**To inscribe a square in a given circle.**

CONSTRUCTION.—In Fig. 47, the circle $A\ B\ C\ D$ is $3\frac{1}{2}''$ in diameter. Draw two diameters, $A\ C$ and $D\ B$, at right angles to each other. Draw the lines $A\ B$, $B\ C$, $C\ D$, and $D\ A$, joining the points of intersection of these diameters with the circumference of the circle, and they will be the sides of the square.

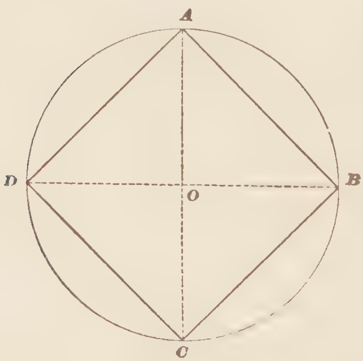


FIG. 47

Problem 15—**To inscribe a regular hexagon in a given circle.**

Construction.—In Fig. 48, from *O* as a center, with the dividers set to $1\frac{3}{4}''$, describe the circle *A B C D E F*. Draw the diameter *D O A*, and from the points *D* and *A*, with the dividers set equal to the radius of the circle, describe arcs intersecting the circle at *E*, *C*, *F*, and *B*. Join these points by straight lines, and they will form the sides of the hexagon. This problem completes Plate III.

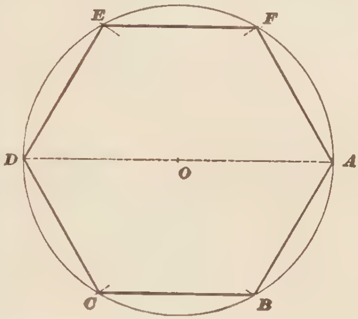


Fig. 48

PLATE IV

38. The first four problems on this plate are more difficult than any on the preceding plates and will require very careful construction. All the sides of each polygon must be of exactly the same length, so that they will space around evenly with the dividers. The figures should not be inked in until the pencil construction is done accurately. The preliminary directions for this plate are the same as for the preceding ones.

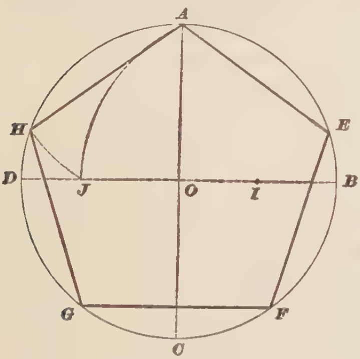


Fig. 49

Problem 16.—**To inscribe a regular pentagon in a given circle.**

Construction.—In Fig. 49, from *O* as a center, with the dividers set to $1\frac{3}{4}''$, describe the circle *A B C D*. Draw the two diameters *A C* and *D B* at right angles to each other. Bisect one of the radii, as *O B*, at *I*. With *I* as a center, and *I A* as a radius, describe the arc *A J* cutting *D O* at *J*.

With *A* as a center, and *A J* as a radius, describe an arc *J H* cutting the circumference at *H*. The chord *A H* is one side of the pentagon.

PROBLEM 17.—**To inscribe a regular octagon in a given circle.**

CONSTRUCTION.—In Fig. 50, from *O* as a center, with the dividers set to $1\frac{3}{4}''$, describe the circle *A B C D E F G H*. Draw the two diameters *A E* and *G C* at right angles to each other. Bisect one of the four equal arcs, as *A G* at *H*, and draw the diameter *H O D*. Bisect another of the equal arcs, as *A C* at *B*, and draw the diameter *B O F*. Straight lines drawn from *A* to *B*, from *B* to *C*, etc. will form the required octagon.

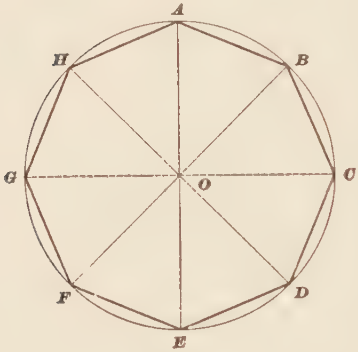


FIG. 50

PROBLEM 18.—**To inscribe a regular polygon of any number of sides in a given circle.**

CONSTRUCTION.—In Fig. 51, from *O* as a center, with the dividers set to $1\frac{3}{4}''$, describe the circle *A 7 C D*. Draw the two diameters *D 7* and *A C* at right angles to each other. Divide the diameter *D 7* into as many equal parts as the polygon has sides (in this case seven). Prolong the diameter *A C* and make *3′A* equal to three-fourths of the radius *O A*. Through *3′* and *2*, the second division from *D* on the diameter *D 7*, draw the line *3′I*, cutting the circumference at *I*. Draw the chord *D I*, and it is one side of the required polygon. The others may be spaced off around the circumference.

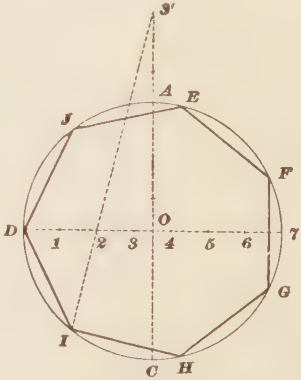


FIG. 51

PROBLEM 19.—**The side of a regular polygon being given, to construct the polygon.**

CONSTRUCTION.—In Fig. 52, let *A C* be the given side. If the polygon is to have eight sides, the line *A C* should be, for this plate, $1\frac{1}{4}''$ long. Produce *A C* to *B*. From *C* as center, with a radius equal to *C A*, describe the semicircle *A 1 2 3 4 5 6 7 B*, and divide it into as many equal parts as there are sides in the required polygon (in this case eight). From the point *C*, and through the second division from *B*, as *6*, draw the straight line *C 6*. Bisect the lines *A C* and *C 6* by perpendiculars intersecting in *O*. From *O* as a center, and with *O C* as a radius, describe the circle *C A H G F E D 6*. From *C*, and through the points *1*, *2*, *3*, *4*, *5* in the semicircle, draw lines *C H*, *C G*, *C F*, etc., meeting the circumference. Joining the points *6* and *D*, *D* and *E*, *E* and *F*, etc., by straight lines, will complete the required polygon.

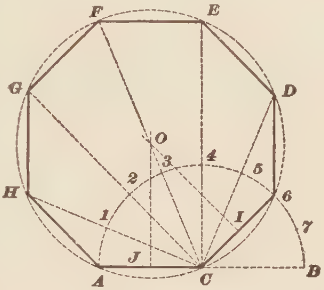


FIG. 52

PROBLEM 20.—**To find an arc of a circle having a known radius, which shall be equal in length to a given straight line.**

NOTE.—There is no exact method, but the following approximate method is close enough for all practical purposes, when the required arc does not exceed $\frac{1}{6}$ of the circumference.

CONSTRUCTION.—In Fig. 53, let *A C* be the given line $3\frac{1}{2}''$ long. At *A*, erect the perpendicular *A O*, and make it equal in length to the given radius, say $4''$ long.

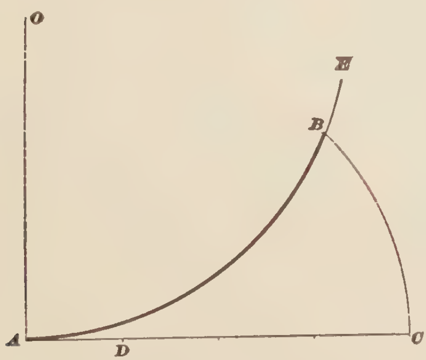


FIG. 53

With OA as a radius, and O as a center, describe the arc ABE. Divide AC into four equal parts, AD being the first of these parts, counting from A. With D as a center, and a radius DC, describe the arc CB intersecting ABE in B. The length of the arc AB very nearly equals the length of the straight line AC.

PROBLEM 21.—**An arc of a circle being given, to find a straight line of the same length.**

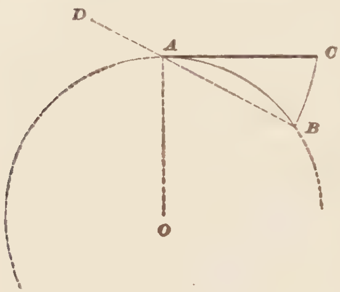


FIG. 54

This is also an approximate method, but close enough for practical purposes, when the arc does not exceed $\frac{1}{6}$ of the circumference.

CONSTRUCTION.—In Fig. 54, let AB be the given arc; find the center O of the arc, and draw the radius OA. For this problem, choose the arc so that the radius will not exceed $1\frac{3}{4}''$. At A, draw AC perpendicular to the radius (and, of course, tangent to the arc). Draw the chord AB, and prolong it to D, so that $AD = \frac{1}{2}$ the chord AB. With D as a center, and a radius DB, describe the arc BC cutting AC in C. AC will be very nearly equal to the arc AB.

PLATE V

39. On this plate there are five problems instead of six. It should be divided into six equal parts or divisions, as the previous ones. The two right-hand end divisions are used to draw in the last figure of Plate V, which is too large to put in one division.

PROBLEM 22.—**To draw an egg-shaped oval.**

CONSTRUCTION.—In Fig. 55, on the diameter AB, which is $2\frac{3}{4}''$ long, describe a circle $ACBG$. Through the center O,

draw OC perpendicular to AB, cutting the circumference $ACBG$ in C. Draw the straight lines BCF and ACE. With B and A as centers, and the diameter AB as a radius, describe arcs terminating in D and H, the points of intersection with BF and AE. With C as a center, and CD as a radius, describe the arc DH. The curve $ADHBG$ is the required oval.

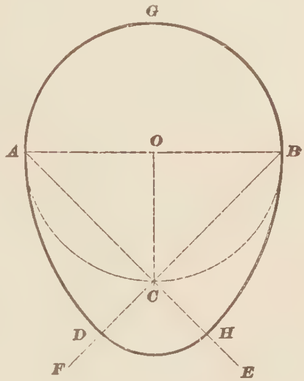


FIG. 55

PROBLEM 23.—**To draw an ellipse, the diameters being given.** The exact method.

CONSTRUCTION.—In Fig. 56, let BD, the long diameter, or major axis, which is $3\frac{1}{2}''$ long, and AC, the short diameter, or minor axis, which is $2\frac{1}{4}''$ long, intersect at right angles to each other in the center O, so that $DO = OB$ and $AO = OC$. With O as a center, and OC as a radius, describe a circle; with the same center, and OD as a radius, describe another circle. Divide both circles into the same number of equal parts, as *1–2*, *2–3*, etc. This is best done by first dividing the larger circle into the required number of parts, beginning at the center line AC, and then drawing radial lines through the points of division on this circle, to the center O of the circles, as shown in the upper right-hand quarter of the figure. The radial lines will divide the smaller circle into the same number of parts that the larger one has been divided into. Through the points of division on the smaller circle, draw horizontal lines, and, through the points of division on the larger circle, draw vertical

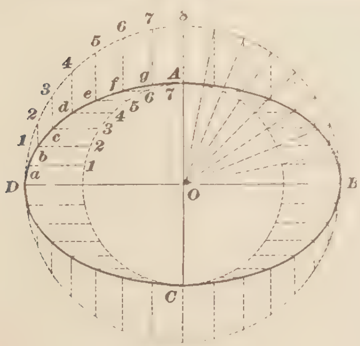


FIG. 56

lines; the points of intersection of these lines are points on the ellipse. Thus, the horizontal line *3c* and the vertical line *3c* intersecting at *c* give the point *c* of the ellipse. Trace a curve through the points thus found by placing an irregular curve on the drawing in such a manner that one of its bounding lines will pass through three or more points, judging with the eye whether the curve so traced bulges out too much or is too flat. Then adjust the curve again, so that its bounding line will pass through several more points, and so on, until the curve is completed. Care should be taken to make all changes in curvature as gradual as possible, and all curves drawn in this manner should be drawn in pencil before being inked in. It requires considerable practice to be able to draw a good curved line in this manner by means of an irregular curve, and the general appearance of a curve thus drawn depends a great deal upon the student's taste and the accuracy of his eye.

PROBLEM 24.—**To draw an ellipse by circular arcs.**

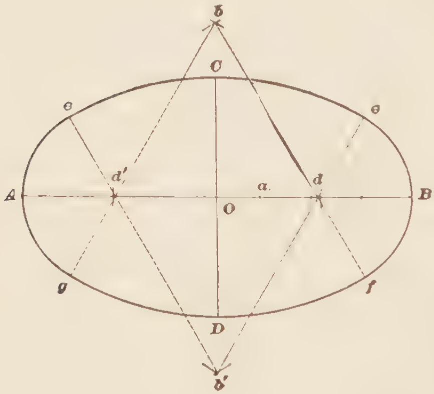


FIG. 57

This is not a true ellipse, but is very convenient for many purposes.

CONSTRUCTION.—In Fig. 57, use the same dimensions as before. On the major axis $A\,B$, set off $A\,a = C\,D$, the minor axis, and divide $a\,B$ into three equal parts. With O as a center, and a radius equal to the length of two of these parts, describe arcs cutting $A\,B$ in d and d'. Upon $d\,d'$ as a side, construct two equilateral triangles $d\,b\,d'$ and $d\,b'\,d'$. With b as a center, and a radius equal to $b\,D$, describe the arc $g\,D\,f$ intersecting $b\,d\,f$ and $b\,d'\,g$ in f and g. With the same radius, and b' as a center, describe the arc $e\,C\,e$

intersecting $b' d' c$ and $b' d e$ in c and e. With A and B as centers, and a radius equal to the chord of the arcs $A c$ or $B e$, describe arcs cutting $A B$ very near to d' and d. From the points of intersection of these arcs with $A B$ as centers, and the same radius, describe the arcs $c A g$ and $e B f$.

PROBLEM 25.—**To draw a parabola, the axis and longest double ordinate being given.**

EXPLANATION.—The curve shown in Fig. 58 is called a **parabola.** This curve and the ellipse are the bounding

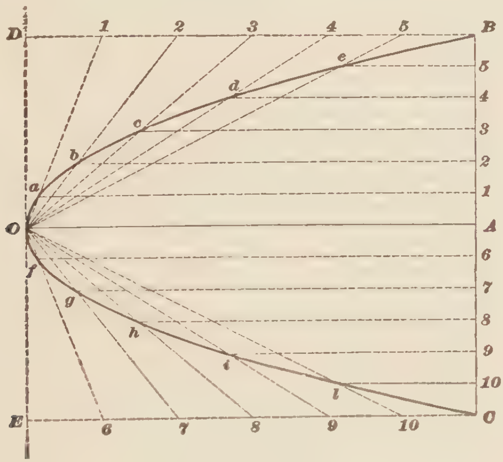


FIG. 58

lines of certain sections of a cone. The line $O A$, which bisects the area included between the curve and the line $B C$, is called the **axis.** Any line, $B A$ or $A C$, drawn perpendicular to $O A$, and whose length is included between $O A$ and the curve, is called an **ordinate.** Any line, as $B C$, both of whose extremities rest on the curve, and is perpendicular to the axis, is called a **double ordinate.** The point O is called the **vertex.**

CONSTRUCTION.—Make the axis $O A$ equal to $3\frac{1}{2}''$, and the longest double ordinate $B C$ equal to $3''$. $B A$, of course, equals $A C$. Draw $D E$ through the other extremity of the

axis and perpendicular to it; also draw *B D* and *C E* parallel to *O A* and intersecting *D E* in *D* and *E*. Divide *D B* and *A B* into the same number of equal parts, as shown (in this case six); through the vertex *O*, draw *O 1*, *O 2*, etc. to the points of division on *D B*, and through the corresponding points *1*, *2*, etc., on *A B*, draw lines parallel to the axis. The points of intersection of these lines, *a*, *b*, *c*, etc., are points on the curve, through which it may be traced. In a similar manner, draw the lower half *O f g h i l C* of the curve.

PROBLEM 26.—**To draw a helix, the pitch and the diameter being given.**

EXPLANATION.—The helix is a curve formed by a point moving around the cylinder and at the same time advancing along its length a certain distance; this forms the winding curved line shown in Fig. 59. The center line *A O*, drawn through the cylinder, is called the **axis** of the helix, and any line perpendicular to the axis and terminated by the helix is of the same length, being equal to the radius of the cylinder. The distance *B 12* that the point advances lengthwise during one revolution is called the **pitch.**

CONSTRUCTION.—As mentioned before, this figure occupies two spaces of the plate. The diameter of the cylinder is $3\frac{1}{2}''$, the pitch is $2''$, and a turn and a half of the helix is to be shown. The rectangle *F B E D* is a side view of the cylinder, and the circle *1'*, *2'*, *3'*, *4'*, etc. is a bottom view. It will be noticed that one-half of a turn of the helix is shown dotted; this is because that part of it is on the other side of the cylinder, and cannot be seen. Lines that are hidden are drawn dotted. Draw the axis *O A* in the center of the space. Draw *F D* $3\frac{1}{2}''$ long and $4''$ from the top border line; on it construct a rectangle whose height $F B = 3''$. Take the center *O* of the circle $2\frac{3}{4}''$ below the point *H* on the axis *A O*, and describe a circle having a diameter of $3\frac{1}{2}''$, equal to the diameter of the cylinder. Lay off the pitch from *B* to *12* equal to $2''$, and divide it into a convenient number of equal parts (in this case 12), and divide the circle into the same

number of equal parts, beginning at one extremity of the diameter *12′ O 6′*, drawn parallel to *B E*. At the point *1′* on the circle divisions, erect *1′–1′* perpendicular to *B E*; through the point *1* of the pitch divisions, draw *1–1′* parallel to *B E*, intersecting the perpendicular in *1′*, which is a point on the helix. Through the point *2′*, erect a perpendicular *2′–2′*, intersecting *2–2′* in *2′*, which is another point on the helix.

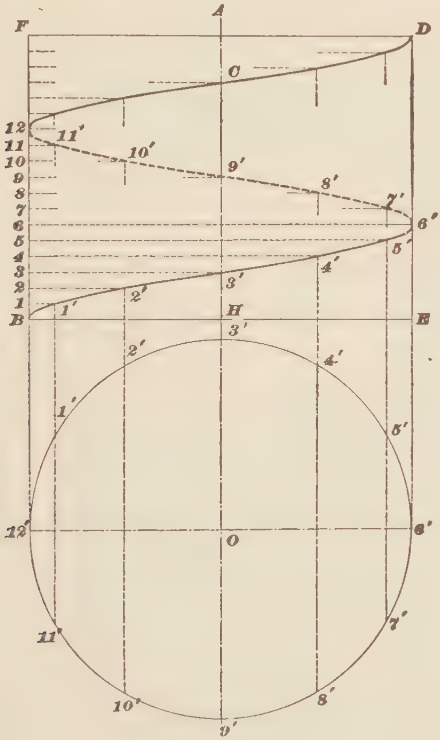


FIG. 59

So proceed until the point *6* is reached; from here on, until the point *12* of the helix is reached, the curve will be dotted. It will be noticed that the points of division *7′*, *8′*, *9′*, *10′*, and *11′* on the circle are directly opposite the points *5′*, *4′*, *3′*, *2′*, and *1′*; hence, it was not necessary to draw the lower half of the circle, since the point *5′* could have been the

starting point, and the operation could have been conducted backwards to find the points on the dotted upper half of the helix. The other full-curved line of the helix can be drawn in exactly the same manner as the first half.

This ends the subject of practical geometry. Mechanical drawing, or the representation of objects on plane surfaces, will now be commenced.

THE REPRESENTATION OF OBJECTS

40. There are five kinds of lines used in mechanical drawing, thus:

The light full line.

The dotted line.

The broken-and-dotted line.

The broken line.

The heavy full line.

The light full line is used the most; it is used for drawing the outlines of figures, and all other parts that can be seen by the eye.

The dotted line, consisting of a series of very short dashes, is used in showing the position and shape of that part of the object represented by the drawing which is concealed from the eye in the view shown; for example, a hollow prism closed on all sides. The hollow part cannot be seen; hence its size, shape, and position are represented by dotted lines.

The broken-and-dotted line, consisting of a long dash, and two dots or very short dashes repeated regularly, is used to indicate the center lines of the figure or parts of the figure, and also to indicate where a section has been taken when a sectional view is shown. This line is sometimes used for construction lines in geometrical figures.

The broken line, consisting of a series of long dashes, is used in putting in the dimensions, and serves to prevent the dimension lines from being mistaken for lines of the drawing.

The heavy full lines are made not less than twice as thick as the light full lines, and are used for shade lines.

Further explanations in regard to these lines will be given when the necessity for using them arises.

41. The illustrations in this and the following paragraphs should be carefully studied, but the student is not required to send in drawings from same. In Fig. 60 is shown a perspective view of a frustum of a pyramid having a rectangular base and a hole passing through the center of the frustum. This figure represents the frustum as it actually appears when the eye of the observer is in a certain position. The angles at *A*, *B*, *C*, and *D* are right angles, the hole is round, and the sides *A B* and *D C* are of equal lengths; so also are *A D* and *B C*; but, if they were measured on the drawing, it would be found that their lengths are all different. The same difficulty would be met with in trying to measure the angles and edges of the sides *A B F E*, *B F G C*, etc. The real length of any line can be found only by a person perfectly familiar with perspective drawing, and then only with great difficulty. Consequently, this method of representing objects is of no use to a patternmaker, carpenter, machinist, or engineer, except to show what the object looks like. In order to represent the object in such a manner that any line or angle can be measured directly, what is termed **projection drawing**, or *orthographic projection*, is universally employed. In the perspective drawing shown in Fig. 60, three sides of the frustum are shown, and the other three are hidden; in a projection drawing, but one side is usually shown, the other five being hidden.

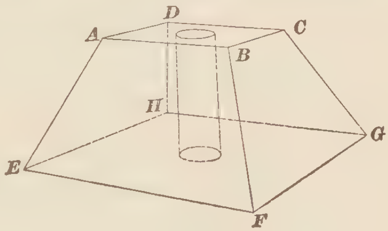


FIG. 60

A line or surface is *projected* upon a plane, by drawing perpendicular lines from points on the line or surface to the plane, and joining them.

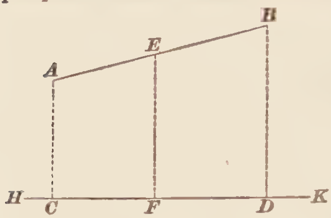


FIG. 61

Thus, if perpendiculars be drawn from the extremities of a line, as AB, to another line HK, as shown in Fig. 61, that portion of HK included between the feet of these perpendiculars is called the **projection** of AB upon HK. Thus, CD is the projection of AB upon HK, the point C is the projection of the point A upon HK, and the point D is the projection of the point B upon HK.

The projection of any point of AB, as E, can be found by drawing a perpendicular from E to HK, and the point where this perpendicular intersects HK is its projection. In this case, the point F is the projection of the point E upon HK.

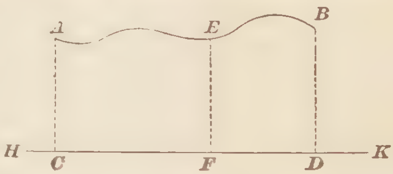


FIG. 62

It makes no difference whether the line is straight or curved—the method of finding the projection is exactly the same. See Fig. 62.

In a similar way, a surface is projected upon a flat surface. Thus, it is desired to project the irregular surface $abdc$, Fig. 63, upon the flat surface $ABDC$. Draw the lines aa', bb' perpendicular to the flat surface; join the points a' and b', where these perpendiculars intersect the flat surface $ABDC$, by a straight line $a'b'$, and $a'b'$ is the projection of the line ab upon $ABDC$.

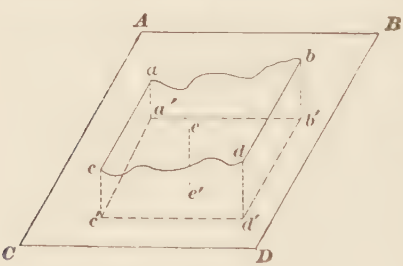


FIG. 63

In the same way, $a'c'$ is found to be the projection of ac; $c'd'$, the projection of cd; and $d'b'$, the projection of db. Hence, the projection of the irregular

surface $a\,b\,d\,c$ upon the flat surface $A\,B\,D\,C$ is the quadrilateral $a'\,b'\,d'\,c'$.

The projection of any point, as e, is found as before, by drawing a perpendicular from the point e to the surface; thus, c' is the projection of the point e upon the plane $A\,B\,D\,C$.

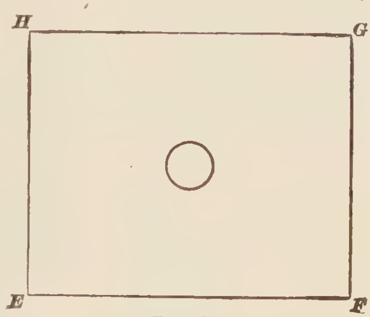


FIG. 64

Suppose that the frustum, Fig. 60, were placed on a plane surface (a surface perfectly flat, like a surface plate), and the outline of the bottom were traced by passing a pencil along its edges, including the round hole, the result would look like Fig. 64, in which the rectangle $E\,F\,G\,H$ represents the bottom of the frustum and the circle represents the hole.

The angles and lengths of the sides are exactly the same as they are on the frustum itself; a similar drawing could be made to represent the top, but it is unnecessary, for the reason that the top can be projected on Fig. 64, and both objects accomplished in one drawing. Fig. 65 illustrates the meaning of the last statement. Here $A'\,B'$ is the projection of the edge $A\,B$, Fig. 60; $B'\,C'$, of $B\,C$, etc. $A'\,E'$ is the projection of the edge $A\,E$; $B'\,F'$, of $B\,F$, etc. This drawing shows the figure as it would look if the eye were directly over it. A drawing which represents the object as if it were resting on a horizontal plane, and the observer looking at it from above, is called a **top view,** or **plan.** The line of vision is thus perpendicular to the faces $A\,B\,C\,D$ and $E\,F\,G\,H$ of the frustum. The lines $A\,B$,

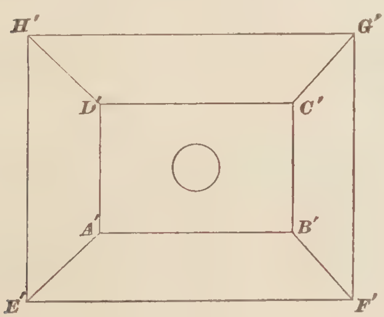


FIG. 65

$B C$, etc., $E F$, $F G$, etc., and the diameter of the hole, can be measured directly. The drawing is not yet complete, since it does not show whether the ends and sides are rounding, hollowed out, or flat. For this purpose, two more views are necessary—*a vertical projection*, or *front view*, commonly called a **front elevation**, and a *side projection*, or **side view.** A front view (elevation) is drawn by imagining the eye to be so situated that the observer looks directly at the front of the object; in other words, the line of vision is parallel to the faces of the frustum. The side looked at is then drawn as if it were projected on a vertical plane at right angles to the horizontal plane, the vertical plane being also parallel to the edges $E F$ and $H G$ of the frustum shown in Fig. 60. The drawing would then look like Fig. 66.

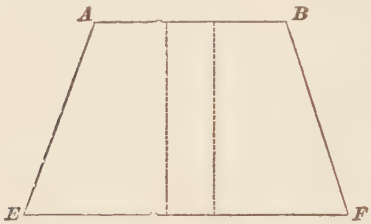


FIG. 66

Here the trapezoid $A B F E$ represents the side $A B F E$ of the frustum; the altitude of the trapezoid being the same as the altitude of the frustum, it can be measured directly. The hole cannot be seen when the observer looks at the frustum in this position; hence, it is indicated by dotted lines. The projections of the lines $A B$ and $D C$ (also, of $E F$ and $H G$, of $A E$ and $D H$, and of $B F$ and $C G$) coincide.

To draw the side view (sometimes called a **side elevation**), imagine the frustum to be revolved around on its axis 90° to the left, and then draw it in precisely the same manner as the front elevation, by projecting the different lines upon a plane at right angles to the horizontal plane, and perpendicular to the edges $E F$ and $H G$, that is, parallel to $B C$ and $F G$. The side elevation would then be drawn as shown in Fig. 67. In this view the lines $A D$

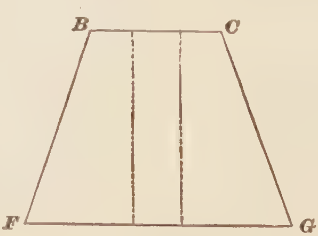


FIG. 67

and BC (also, EH and FG, DH and CG, and AE and BF) coincide.

42. In order to show clearly the different views, and to guard against one view being mistaken for another, they are always arranged on the drawing in a certain fixed and invariable manner. Fig. 68 shows this method of arrangement.

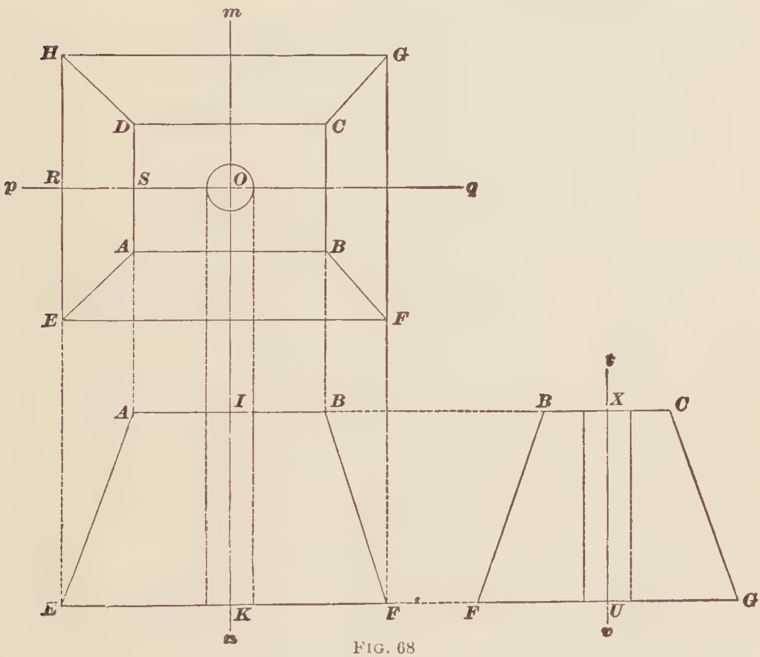


FIG. 68

The plan is drawn first, then the two elevations. It is usually immaterial which of these views is drawn first, but the general arrangement is as shown. Any departure from this method of arrangement should be distinctly specified on the drawing in writing, unless the purpose of the draftsman is so clearly evident that no explanation is needed. The broken and dotted lines are the **center lines**; they serve to show the connection existing between the different views of the object, and to indicate axes of cylindrical surfaces of any

kind. It will be noticed that, in the plan view, the two center lines cross each other at right angles, and that their point of intersection O is the center of the circle which represents the hole. Whenever a circle is drawn, two center lines should also be drawn through its center at right angles to each other; this enables any one looking at a drawing to instantly locate the center of any circle. This remark also applies to ellipses, semicircles etc.

To draw the frustum as shown in the last figure, either the front elevation or the plan is drawn first—whichever happens to be more convenient. Suppose the front elevation to be drawn first. Draw the vertical center line $m\,n$; measure the altitude of the frustum, and lay it off on this line, locating the points I and K; through these points, draw the lines $A\,B$ and $E\,F$ perpendicular to $m\,n$; make $A\,I = I\,B = \frac{1}{2}\,A\,B$, measured on the frustum; also $E\,K = K\,F = \frac{1}{2}\,E\,F$, measured on the frustum, and draw $A\,E$ and $B\,F$. Lay off the radius of the circular hole on both sides of the center line $m\,n$, and draw the dotted lines parallel to $m\,n$ through the extremities of these radii to represent the hole. The front elevation is now complete. To draw the plan, decide where the center is to be located on $m\,n$, and draw the horizontal center line $p\,q$. With the point of intersection O of the two center lines as a center, and with a radius equal to the radius of the hole, describe a circle. Through the points A, B, E, and F, draw indefinite straight lines parallel to $m\,n$. On both sides of the center line $p\,q$, lay off on these lines $D\,S$ and $S\,A$, equal to $\frac{1}{2}\,D\,A$, and $H\,R$ and $R\,E$, equal to $\frac{1}{2}\,H\,E$, both $D\,A$ and $H\,E$ being measured on the frustum. Through the points H, E, D, and A, draw the lines $H\,G$, $E\,F$, $D\,C$, and $A\,B$, and join the points H and D, E and A, F and B, and G and C by straight lines, as shown. The figure thus drawn will be the plan.

To draw the side elevation, prolong the lines $A\,B$ and $E\,F$, and draw the center line $t\,v$. Lay off, on each side of $t\,v$, $F\,U$ and $U\,G$ equal to $\frac{1}{2}\,F\,G$, measured on the frustum, and $B\,X$ and $X\,C$ equal to $\frac{1}{2}\,B\,C$, measured on the frustum. Join B and F, and C and G, by the straight lines

B F and *C G*, and draw the hole dotted as in the front elevation. The drawing is now complete.

The student should have by this time a good idea of how simple objects may be represented by the different views of a drawing, and can now begin on the next plate.

DRAWING PLATE, TITLE: PROJECTIONS—I

43. In making actual drawings of objects when the size of the plate is limited, it is usually impossible to divide it up into a certain number of parts, as in the case of the preceding plates, for the various figures differ widely in their sizes. These drawings should be so made that no part shall come nearer than $\frac{3}{4}''$ to the border line, and the figures should be so arranged as to present a pleasing appearance to the eye, and not be scattered aimlessly all over the drawing.

Fig. 1 represents a **rectangular prism** $2''$ long, $1\frac{1}{2}''$ wide, and $\frac{3}{4}''$ thick. The prism is represented as if it were standing on one of its small ends, with the broad side towards the observer. The elevation *A B D C* is drawn first; in this case, it will be a rectangle $2'' \times 1\frac{1}{2}''$. The top view, or plan, *F E B A* is next drawn; this is a rectangle $1\frac{1}{2}'' \times \frac{3}{4}''$, the side *A B* being the projection of the front of the prism, and the side *F E* of its back. Lastly, the side elevation is drawn; this is another rectangle *B E H D*, $2'' \times \frac{3}{4}''$, the side *B D* representing the projection of the front of the prism, and the side *B E* corresponding to the right-hand end *B E* of the plan.

Fig. 2 is a **wedge** standing on one of its triangular ends. It is the rectangle shown in Fig. 1, cut diagonally through the corner from *E* to *A* on the plan. It will be noticed that the two elevations are exactly the same as in Fig. 1, the plan showing the difference between the two figures.

Fig. 3 is another wedge, standing on one of its rectangular sides, formed by cutting through the prism, in Fig. 1, from *A* to *D*. The plan and side elevation are the same as in Fig. 1. Here, the front elevation shows the difference

between Figs. 1 and 3. The point D of the elevation is projected on the plan in the point D, and the point opposite D, perpendicular to the plane of the paper, is the point H, shown in all of the side elevations.

Fig. 4 is also a wedge; it is formed by cutting through the prism in Fig. 1 from B to H. The front elevation and plan are the same as shown in Fig. 1, the side elevation being different. The point H in the side elevation opposite D is here projected in the point H of the plan; the point opposite C in the front elevation, and opposite H in the side elevation, is projected in the point K of the plan, the line $K H$ being opposite $C D$ in the plane of the base.

Fig. 5 shows a **cylinder** $1\frac{1}{4}''$ in diameter and $2''$ long. The side elevation is not given, since all elevations of a cylinder whose bases are perpendicular to its axis are the same. Either view may be drawn first, according to convenience.

Fig. 6 shows a **hexagonal prism** $2''$ long; the distance between any two parallel sides is $1\frac{1}{4}''$. In this case, the plan (a regular hexagon) must be drawn first. It is desired also that two of the parallel sides shall be horizontal. To draw the plan in this position, with the dimensions given, choose the center O of the hexagon; draw two center lines at right angles to each other, as $m n$ and $p q$. With O as a center, and a radius equal to one-half of the distance between two parallel sides ($1\frac{1}{4}'' \times \frac{1}{2} = \frac{5}{8}''$), describe a circle. Now, use the T square to draw two horizontal lines through the points of intersection of this circle with the center line $m n$. By means of the T square and 60° triangle, draw $A B$ and $C D$ through O, in such a manner that the angles $A O q$ and $C O p$ each equal 60°; this is done by keeping the longer of the two short sides of the triangle vertical, and passing the pencil along the hypotenuse. Through E and H, the points of intersection of $A B$ with the two parallel lines, draw $E K$ and $H G$ parallel to $C D$; and through F and I, the points of intersection of $C D$ with the two parallels, draw $F G$ and $K I$ parallel to $A B$. This completes the hexagon, and also the plan of the prism. To draw the front elevation, measure

off, on the center line *m n*, the distance *J L* equal to 2″, and through the points *J* and *L* draw the two horizontal lines *S e* and *R f*. Project the points *K*, *I*, *H*, and *G* upon *S e*, as shown by the dotted lines; and through the points of intersection of these dotted lines with *S e*, draw the vertical lines *S R*, *a b*, *c d*, and *e f*, thus completing the front elevation. To draw the side elevation, extend the lines *S e* and *R f*, and draw the center line *t v*. Make *U W* equal to $1\frac{1}{4}''$, which is equal to the distance between the parallel sides, and draw *U X* and *W Y*; also, *M Z*, the point *M* corresponding to the point *K* of the plan.

Fig. 7 represents a **hexagonal pyramid**; the distance between two parallel sides of the base is $1\frac{1}{4}''$, and the altitude is 2″. As in Fig. 6, the plan must be drawn first. Then, to draw the front elevation, lay off *O I* on the center line *m n* equal to the altitude, and through *I* draw the base line *A′D′*. Project the points *D*, *E*, etc. of the plan upon *A′D′*, as shown by the dotted lines, and join them with the point *O* by the straight lines *A′O*, *F′O*, *E′O*, and *D′O*; these lines are the vertical projections of the edges of the pyramid; the horizontal projections of the edges are *F O*, *E O*, *D O*, etc. The side elevation can be easily drawn, and does not require a special description, the length of the base *B F* being equal to the distance between the parallel sides, or $1\frac{1}{4}''$.

Fig. 8 shows a **rivet** $\frac{7}{8}''$ in diameter, having a button head $1\frac{1}{2}''$ in diameter. The side elevation is not given, since it is exactly the same as the front elevation. Either of the two views may be drawn first, according to convenience. Suppose that the elevation is first drawn. Draw the center line *m n*, and the line *A B* for the base of the head. On the center line lay off from the line *A B*, or the base of the head, a point *O*, at a distance of $\frac{17}{32}''$, the height of the head. With the compasses set to a radius of $\frac{51}{64}''$, and from a point on the center line *m n*, describe an arc *A O B*, taking care to pass this arc through the point *O*. Lay off from, and on both sides of, the center line *m n* a distance of $\frac{7}{16}''$, or $\frac{1}{2}$ of the diameter of the rivet, and draw *E G* and *F H*. Draw the other center line *p q* of the plan, and with *O* as a center,

and a radius equal to the radius of the button head, describe a circle. With the same center, and a radius equal to $\frac{7}{16}''$, describe the dotted circle, the horizontal projection of the rivet. The irregular line $G H$ indicates that only a part of the rivet is shown. This is done so as not to take up too much space on the drawing.

Fig. 9 shows an ordinary **square-headed bolt** $\frac{7}{8}''$ in diameter, having a head $1\frac{3}{8}''$ square and $\frac{13}{16}''$ thick. Draw the center lines $m n$ and $p q$. Construct the rectangle $A B D C$, $1\frac{3}{8}'' \times \frac{13}{16}''$, the elevation of the head. Locate the points E and F at a distance of $\frac{7}{16}''$ from each side of the center line, and draw $E G$ and $F H$. With the compasses set to a radius of $1\frac{3}{8}''$ and from a point on the center line $m n$, describe the arc representing the chamfering of the head. Draw the plan of the head $L K B A$ (a square whose edge measures $1\frac{3}{8}''$), and the dotted circle $\frac{7}{8}''$ in diameter, the projection of the body of the bolt, which cannot be seen in this view.

Fig. 10 shows a **distance piece** used to separate two other parts, and to keep them a certain distance apart. The arrangement of the views of this figure is somewhat different from the preceding ones, in order to make room for it on the drawing. Draw the center line $n m$, and construct the figure according to the dimensions marked on the plate. Use a radius of $\frac{1}{8}''$ for the fillets at A, B, C, and D, and an equal radius to round the corners at E, F, G, and H.

Fig. 11 shows a **square cast-iron washer.** Instead of making an elevation and plan as usual, a section is taken through $p q$; that is, the washer is imagined to be cut on the line $p q$, with all that part of the figure to the left of $p q$ removed, and an elevation drawn of the remaining part. In order to distinguish a sectional drawing without any possibility of mistake, the so-called section lines are employed. These are usually drawn by laying a 45° triangle against the edge of the T square, and drawing a series of parallel lines as nearly equally distant apart as can be judged by the eye. For cast iron, these lines are full, thin lines, all of the same

thickness, and must not be drawn too near together. The method of sectioning for other materials will be given later on. It is not usual to draw the section lines in pencil, but to wait until the outlines of the drawing have been inked in, and then section directly with the drawing pen. The shortest distance apart of the section lines should rarely be *less* than $\frac{1}{16}''$, unless the drawing is of such small dimensions as to cause a sectioning of this width to look coarse. This is the case with Figs. 11 and 12 of this plate. In these two figures make the section lines a full $\frac{1}{32}''$ apart. Only that part of the figure is sectioned which is touched by the cutting plane, the rest of the figure being drawn as if it were projected upon the cutting plane. The corners of this figure should be rounded with a radius of $\frac{1}{16}''$; the other dimensions can be obtained from the plate.

Fig. 12 is a **cast-iron cylindrical ring.** It is shown in plan and section. The dimensions given suffice for the drawing of the figure without further explanations. The inner circle of plan is the projection of the innermost points of the ring which form a circle whose diameter is $A\,B$.

44. When inking in a drawing, it is generally best to draw the circles and other curved lines first, and the straight lines afterwards. This enables the draftsman to easily blend into one line the straight lines meeting the curves, so that their points of meeting cannot be detected; it enables the tangent lines to be drawn with better success, and also shortens the time of inking in a drawing. It will be noticed that some of the straight lines are heavy and some light, and that parts of the full-line circles are heavy and the rest of the circle light. These are the shade lines; they are described later on. The student may make all of the full lines except the border lines of this plate, and the three following plates, of the same thickness, if he so desires. The dotted lines used to indicate those parts of the figures that are hidden must be of the same thickness as full lines, while the construction lines and center lines should be very thin.

45. Dimensions.—The dimension lines and figures on this and succeeding plates are to be inked in by the student. Make the dimension figures $\frac{3}{32}''$ high, and of the same style as those shown in Art. **20.** Fractions should be $\frac{1}{8}''$ high over all. If there is not room for figures of this size, great care should be taken to make them *clear*.

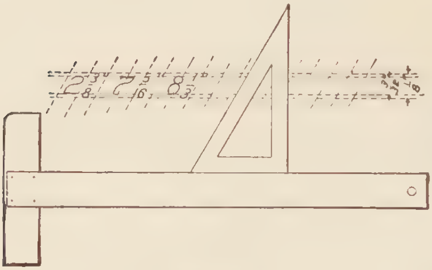


FIG. 69

Until after the student has obtained sufficient practice in lettering, he should draw guide lines in pencil for the dimension figures, as in Fig. 69, unless he can make them look well without. All the figures should have the same slant of 60°, and, when printing fractional dimensions, the *whole* fraction should have the same slant as the figures; that is, the denominator should be under the numerator in a *slanting* direction, and not straight below it. Make the dividing line between the numerator and denominator horizontal, not slanting.

Dimension and extension lines must be light, broken lines of the same thickness as the center and construction lines. Care should be exercised to make the arrowheads as neatly as possible and of a uniform size. They are made with a Gillott's No. 303 pen, and their points must touch the extension lines, as illustrated in Fig. 70. Do not make arrowheads too flaring.

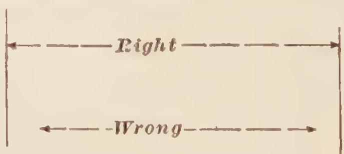


FIG. 70

When putting in the dimensions, care should be taken to give *all* that would be needed to make the piece which the drawing represents, but do not repeat the same dimension on different views. Thus, in Fig. 1 of this plate, the length is given in the front elevation as 2″, and it is obviously unnecessary to give the same dimension in the side elevation.

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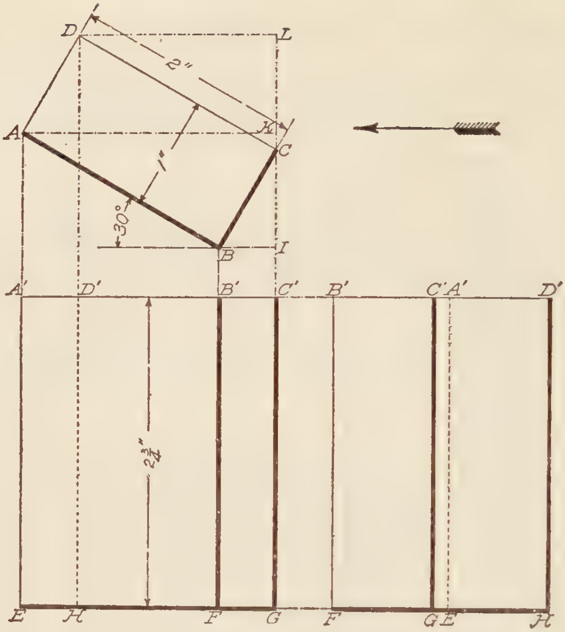
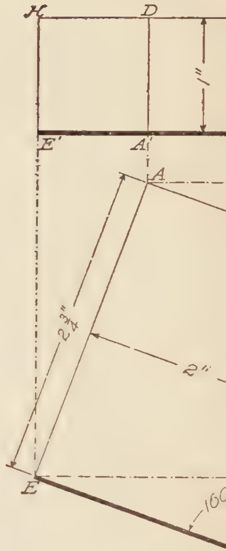


Fig. 1.



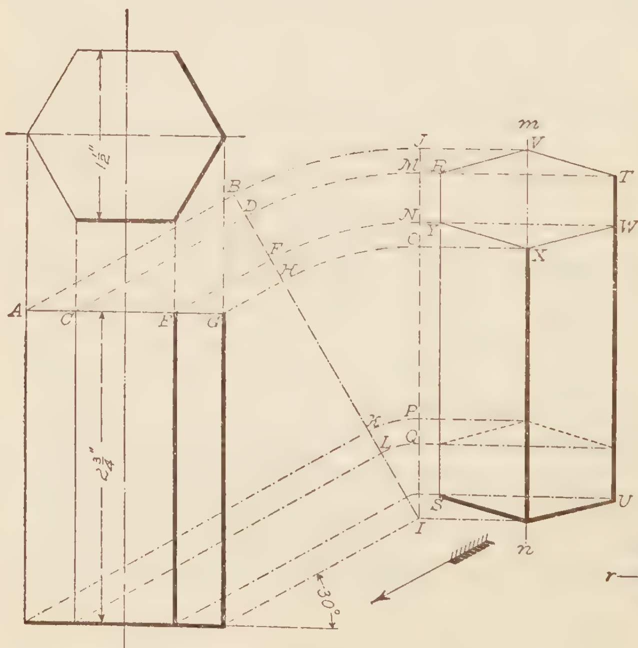


Fig. 4.

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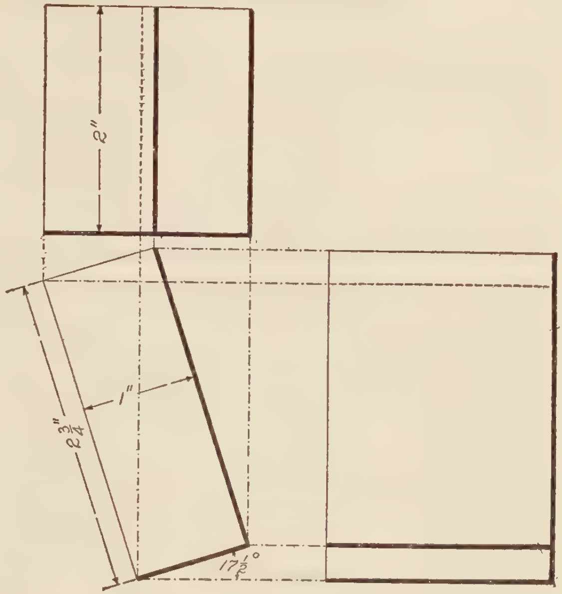


Fig. 3.

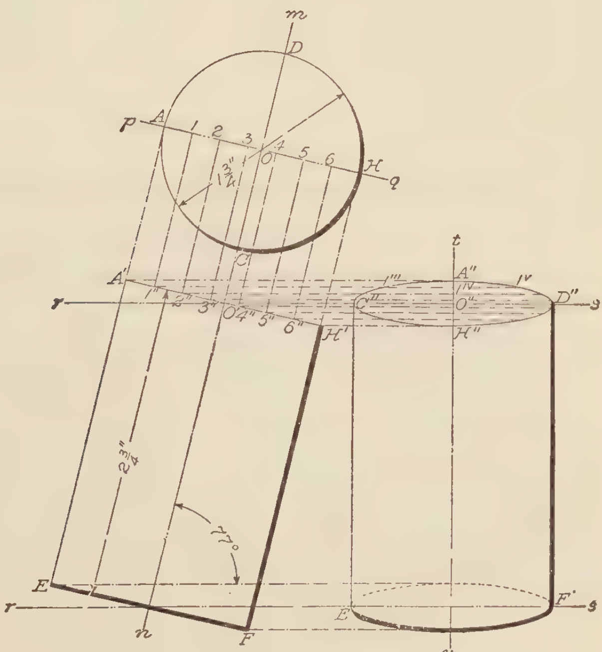


Fig. 6.

JOHN SMITH, CLASS No 4529.

Again, the dimension lines should be put where they would be most likely to be looked for. In Fig. 10 of this plate, the diameter of the central part of the distance piece is marked $1\frac{1}{4}''$ in the elevation; it could have been marked on the side elevation, as the diameter of the dotted circle, but a person wishing to find the size of this part of the piece would naturally look for it in the front elevation. This is also true of the diameter of the flange. The diameter of the hole could be on the plan or elevation, but it is put on the plan because it is denoted there by a full line, while in the elevation the hole is dotted. Never cross one dimension line by another, if it can well be avoided. Thus, in Figs. 2 and 4 of this plate, the bounding lines of the triangular views are extended by fine broken lines, in order that the dimension lines ($\frac{3}{4}''$) may not cross the lines marking the length and width of the wedge.

The student should ink in all the figures used for dimensions shown on this and succeeding plates, on his drawing, but should omit the letters used to describe the different objects. The titles should be made in block letters as shown on sample copies. The date, name, course letter, and class number are to be put on as in the preceding plates.

DRAWING PLATE, TITLE: PROJECTIONS—II

46. The figures on the last plate were drawn under the supposition that the center lines, and at least one flat side, were parallel to the plane of the paper—the center lines were also either vertical or horizontal. This is always possible in detail drawings, where each piece is drawn separately by itself, but in the case of machines, where the parts are placed at different angles, they cannot always be drawn in this manner. The figures on this plate are so drawn that they show objects similar to those in the last plate, but at different angles. The student should exercise particular care to understand this plate and the

two succeeding ones; if he thoroughly masters them, he should experience no great difficulty in the plates that follow.

Fig. 1 shows a **rectangular prism** $2\frac{3}{4}''$ long, $2''$ wide, and $1''$ thick, standing in a perpendicular position on one of its small ends in such a manner that the broad sides make an angle of 30° with a horizontal line. Draw the plan first. To do this, construct the rectangle $ABCD$ $2'' \times 1''$, with the parallel edges AB and DC making an angle of 30° with the horizontal; this may be done by holding the head of the T square against the left-hand end of the board, and using the 60° triangle. To construct the front elevation, draw a horizontal line $A'C'$ and project A upon this line, thus obtaining the point A'. Draw $A'E$ perpendicular to $A'C'$, and make it equal in length to $2\frac{3}{4}''$, the length of the prism. Through E draw EG. Project the points B and C upon $A'C'$, and draw $B'F$ and $C'G$. The back edge $D'H$ of the prism is not seen, and, hence, its position is indicated by the dotted line $D'H$.

The side elevation can be drawn in a similar manner by projecting the points $ABCD$ upon a vertical line, as IL. Produce $A'C'$ and EG, and make $B'D'$ equal to IL. Now use the spacing dividers, and set off $B'C'$ equal to IC, and $B'A'$ equal to IK. Through B', C', A', and D', draw the vertical lines $B'F$, $C'G$, $A'E$, and $D'H$, drawing $A'E$ dotted, because, when looking at the prism in the direction of the arrow, the edge $A'E$ is not seen.

Fig. 2 is the same **prism** shown in Fig. 1, but in a different position. The two broad sides are parallel to the plane of the paper, and the prism is tipped in such a manner that the base makes an angle of 160° with the horizontal. The elevation must be drawn first. To do this, draw a horizontal line; then, by using the protractor, draw the line EF, making an angle of 160° with the horizontal, reckoning from right around to the left, opposite to the motion of the hands of a clock. Make EF equal in length to $2''$, and on it construct the rectangle $EFBA$, $2\frac{3}{4}'' \times 2''$; it will be the vertical

projection or front elevation of the prism. The method of drawing the plan and side elevation is apparent without further explanation.

Fig. 3 is the same **prism** shown in Figs. 1 and 2, but with the narrow sides parallel to the plane of the paper, and tipped until the base makes an angle of $17\frac{1}{2}°$ with the horizontal. The sizes are the same as in the two preceding figures, and it should be drawn without further explanation, the front elevation being drawn first.

Fig. 4 shows a **hexagonal prism** having two of its parallel sides parallel to the plane of the paper, and its axis vertical; instead of a side elevation at right angles to the horizontal, a side elevation is desired, as if the vertical prism were looked at in the direction of the arrow, or at an angle of 30° with the horizontal. Draw the plan first and then the front elevation from the dimensions given. To draw the other view, first draw the center line mn, and then, by use of the T square and 30° triangle, draw the lines AB, CD, EF, and GH, from the points A, C, E, and G, as shown. Also draw in a similar manner the other four dotted lines at the base of the prism; then draw the line IB at a right angle to the lines AB, CD, etc. At the point I, draw the line IJ parallel to the center line mn, and, with I as a center, and the points B, D, F, H, K, L, etc. as radii describe arcs, as shown, cutting the vertical line IJ at the points J, M, N, O, P, Q, etc. Through the points J, M, N, O, P, Q, etc. draw horizontal lines as shown. On each side of the vertical center line mn, lay off a distance of $\frac{3}{4}''$, or one-half the distance between the parallel sides of the prism, which is $1\frac{1}{2}''$, as shown in the plan, and draw the lines RS and TU. This view is then completed by drawing the lines VR, VT, WX, and YX, as shown. The lines at the base are drawn in a similar manner.

Fig. 5 represents a **hexagonal pyramid** whose axis is parallel to the plane of the paper, the base making an angle of 30° with the horizontal. It is desired to find the vertical projection of the side elevation. Having drawn the plan $ABCDEF$ and the side elevation $O'A'B'C'D'$, as shown

from the dimensions marked on the drawing, choose the position of the vertical center line $t\,v$; project O' and O''' upon it in the points O'' and O^{IV}, and, through O^{IV} and O''', draw a fourth center line $r\,s$. On this, lay off $O^{IV}G'$ and $O^{IV}H'$ equal to $O\,G$ and $O\,H$, and construct the projection $A''\,B''\,C''\,D''\,E''\,F''$, as indicated by the broken and dotted lines. Join $O''\,E''$, $O''\,F''$, etc. by straight lines, and it will be the required projection. The figure thus drawn represents the pyramid as it would appear placed so that its base made an angle of 30° with the horizon, the line of vision being horizontal to the observer looking at it from the left side.

Fig. 6 shows a **cylinder** whose axis is parallel to the plane of the paper and makes an angle of 77° with the horizontal. The vertical side projection is required. Draw the plan and front projection as shown from the dimensions given. Draw the center line $t\,v$ vertical, and project the center O' upon it in O''; also, A' in A'', and H' in H''. To find the remaining points on the projected circle, divide the diameter $A\,H$ of the plan into a convenient number of equal parts, in this case 7, as $A\,1$, 1–2, 2–3, etc. Through the points thus laid off, draw the lines 1–$1''$, 2–$2''$, 3–$3''$, etc., parallel to the center line $m\,n$. Through the points A', $1''$, $2''$, $3''$, etc., draw the horizontal lines as shown by the dotted lines. From and on each side of the vertical center line $t\,v$, lay off distances on each side of the horizontal lines just drawn equal to the length of that part of the lines 1–$1''$, 2–$2''$, 3–$3''$, etc. included between the center line $p\,q$ and the semicircle $A\,C\,H$; thus, on the horizontal line drawn through the point O', the distances $O''C''$ and $O''D''$ are each equal to $O\,C$ in the plan. The distances 1^{IV}–$1'''$ and 1^{IV}–1^{V} are each equal to the distance from 1 to the point of intersection of the semicircle on the line 1–$1''$. The remaining distances are laid off in a similar manner. A curve traced through the points thus found will be the required projection of the upper base of the cylinder. The projection of the lower base is found in exactly the same way. Drawing $C''E'$ and $D''F'$ completes the required projection.

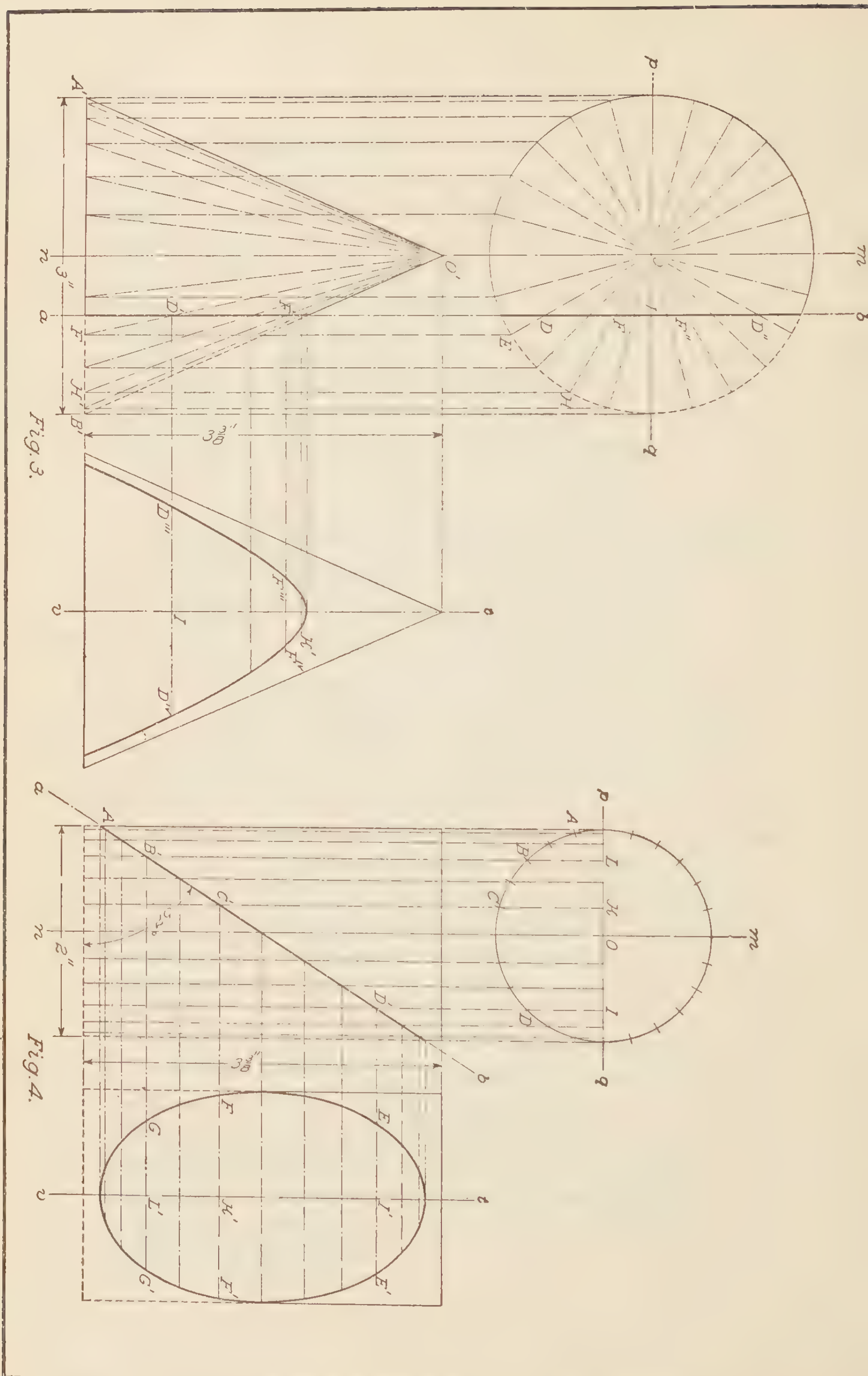
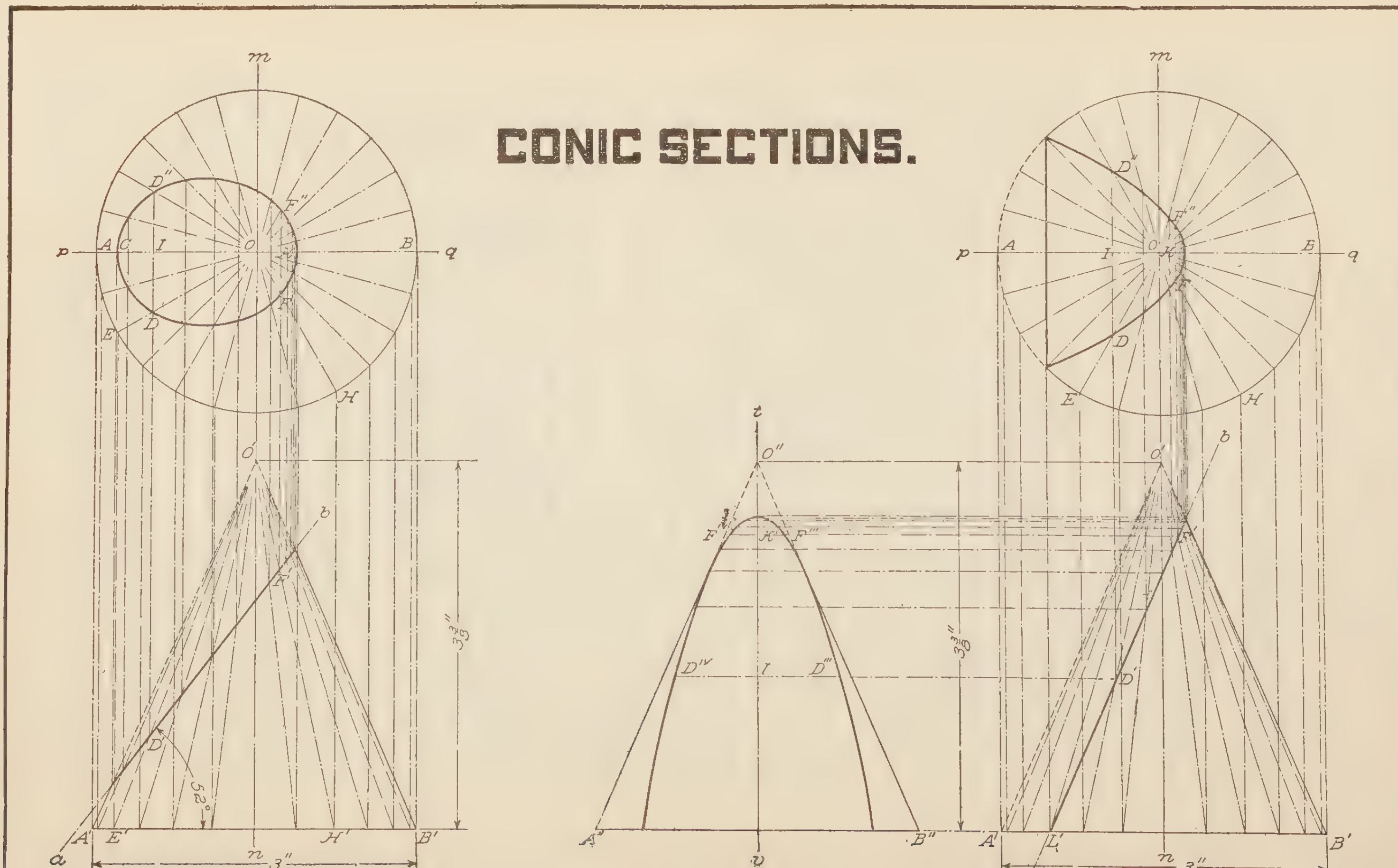


Fig. 3.
Fig. 4.



JOHN SMITH CLASS No 4529.

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DRAWING PLATE, TITLE: CONIC SECTIONS.

47. This plate shows the different forms of the curves formed by the intersection of a cone or cylinder by a plane. If the plane of intersection is perpendicular to the axis of the cone or cylinder, the curve of the intersection will be a circle; but if it is inclined to the axis, it will be an ellipse in the case of a cylinder, and an ellipse, hyperbola, or parabola in the case of a cone, according to the angle of inclination.

Fig. 1 is a **cone cut by a plane** which does not intersect the base of the cone. *When the cutting plane does not intersect the base*, or the new base of the cone when the cone is extended, the curve of intersection is an **ellipse.**

Draw the plan and front elevation of a right cone whose altitude is $3\frac{3}{8}$ inches and whose base is 3 inches in diameter. Cut this cone by a plane $a\,b$, making an angle of 52° with the base. See figure.

Divide the circle which represents the base of the cone in the plan into any number of parts, in this case 24, and, through the points of division A, E, H, etc., draw the radii $O\,A$, $O\,E$, $O\,H$, etc. to the center O. Draw also from these points straight lines $A\,A'$, $E\,E'$, $H\,H'$, $B\,B'$, etc., parallel to the axis of the cone $O'n$, and cutting the base $A'B'$ in the points E', H', etc. From these points, draw lines to the apex O' of the cone, and cutting the base $A'\,B'$ in points E', H', etc. From these points, draw lines to the apex O' of the cone, as $E'O'$, $H'O'$, etc., cutting the plane $a\,b$ in the points D', F', etc. From these points D', F', etc., draw straight lines $F'F\,F''$, $D'D\,D''$, etc., parallel to the axis $O'n$ of the cone, and intersecting the radii $O\,A$, $O\,E$, $O\,H$, $O\,B$, etc., in the points C, D, F, K, F'', D'', etc., and through these points of intersection draw the ellipse by aid of an irregular curve.

Fig. 2 is a cone of the same size as in the preceding problem; but the cutting plane $a\,b$ is, in this case, parallel to one of the elements* of the cone, and intersects the base. The

*Any straight line drawn on the surface of a cone and passing through the apex (as $O'A'$, Fig. 1, or $O'A'$, Fig. 2, etc.) is called an **element.**

curve formed by the intersection of a cone by a plane parallel to one of its elements is called a **parabola.** The plan and front elevations of the cone and curve of intersection are found in a manner similar to the method used in the last problem. To find the side elevation, proceed as follows: Draw the side elevation $O''A''B''$ of the cone with the center line $t\,v$ as its axis. Draw the projection lines $F'F'''F^{IV}$, $D'D'''D^{IV}$, etc., and make $K'F'''$ and $K'F^{IV}$ equal to KF and KF''; make $I'D'''$ and $I'D^{IV}$ equal to ID and ID'', etc., and trace a curve through the points thus found. The result will be the side elevation of the cone when cut by a plane parallel to one of its elements and having the upper part removed. The side elevation of Fig. 1 may be drawn in a similar manner.

Fig. 3 is a cone having the same dimensions as the two preceding problems, but cut by a plane $a\,b$ parallel to the axis of the cone and perpendicular to the vertical plane of projection. When the cutting plane intersects the base of a cone and is not parallel to any element (that is, if the acute angle included between the cutting plane and the base is greater than the angle $O'A'B'$ included between any one element and the base), the curve of intersection is called a **hyperbola.**

The plan and front elevation are constructed as before, the horizontal projection of the curve for this particular case, where the cutting plane is parallel to the axis of the cone, is also a straight line. The side elevation is found as in the last problem, by drawing the lines of projection $F'F'''F^{IV}$, $D'D'''D^{IV}$, etc., and making $I'D'''$ and $I'D^{IV}$ equal to ID and ID'', $K'F'''$ and $K'F^{IV}$, equal to IF and IF'', etc. The curve drawn through the points thus found will be the required hyperbola.

Fig. 4 shows the **intersection of a cylinder,** $3\frac{3}{8}''$ long and $2''$ in diameter, by a plane $a\,b$, making an angle of $57°$ with the base. The plan and elevation may be drawn as shown, the horizontal projection of the curve being a circle, having the same diameter as the base. To construct the side elevation of the curve, divide the circle representing the

INTERSECTIONS AND

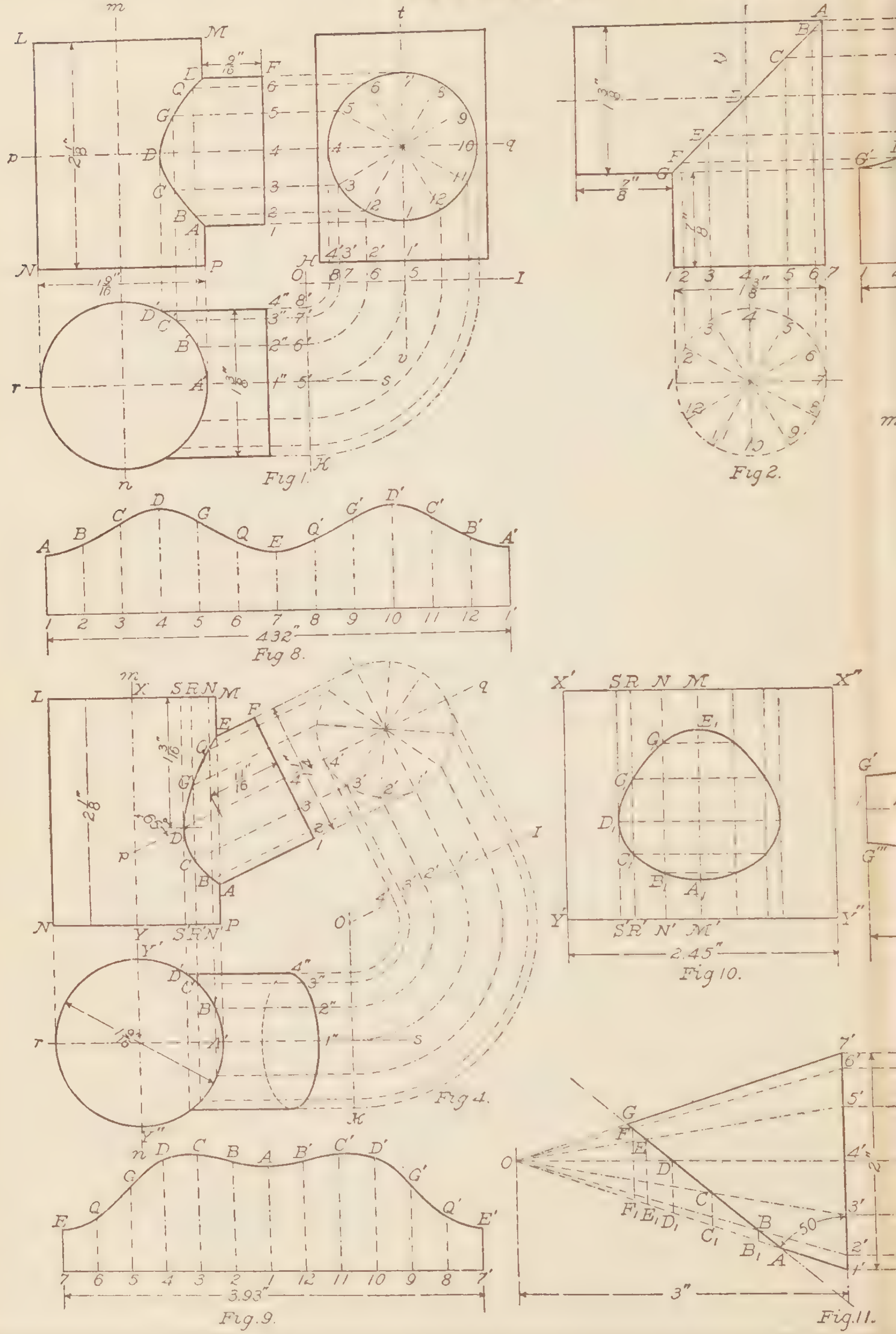

Fig 1. Fig 2. Fig 8. Fig 4. Fig 10. Fig. 9. Fig. 11.

EVELOPMENTS.

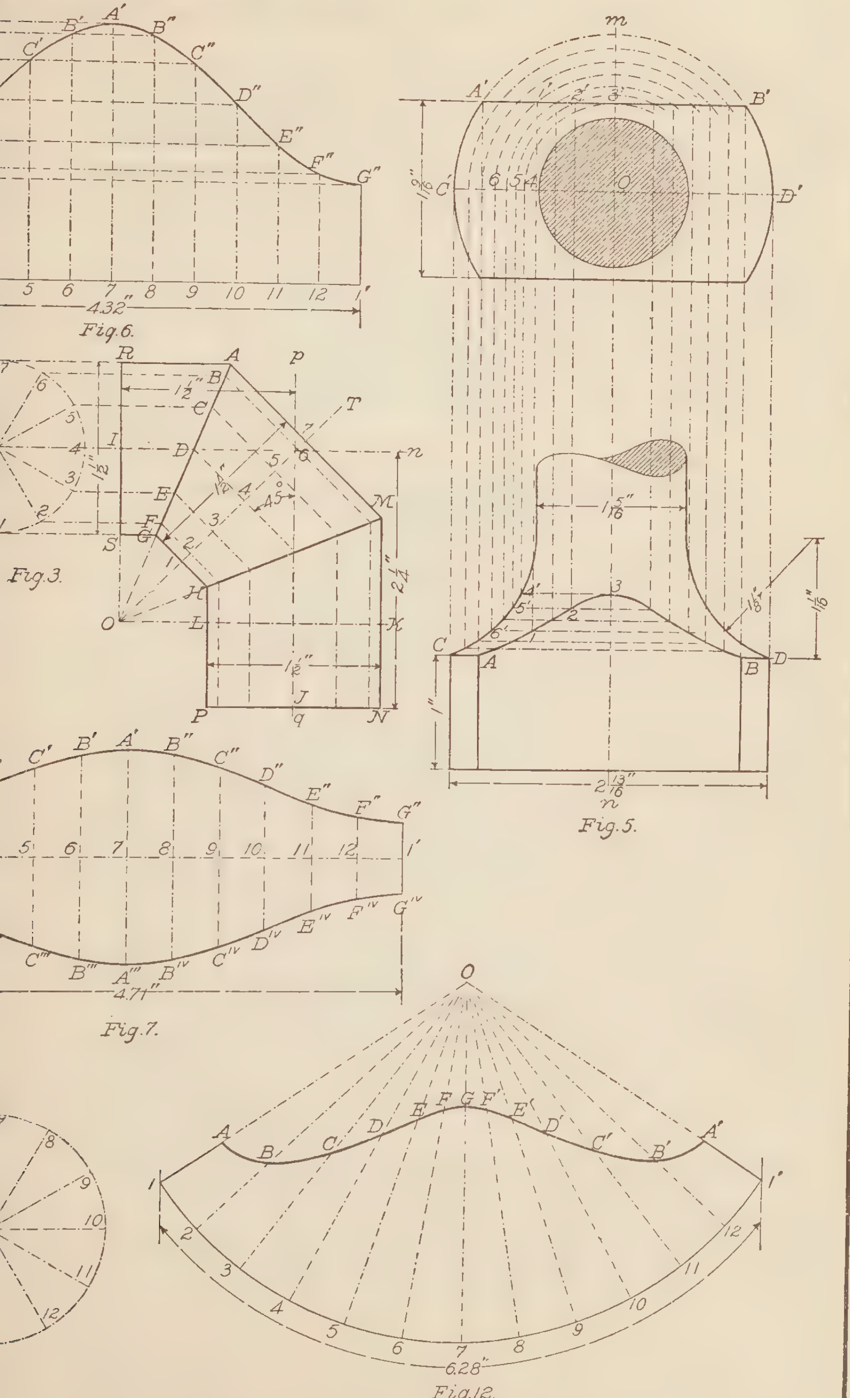

Fig.6.

Fig.3.

Fig.5.

Fig.7.

Fig.12.

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JOHN SMITH, CLASS No 4529.

base of the cylinder in the plan into any number of parts, in this case 24, and through the points of division A, B, C, etc. draw the radii OA, OB, OC, etc. to the center O. Draw also from these points straight lines AA, LBB', KCC', IDD', etc. parallel to the axis mn of the cylinder, and cutting the base in the elevation. From the points A, B', C', D', etc. draw lines $D'E'$, $C'F'$, $B'G'$, etc. at right angles to the axis mn. Make $I'E$ and $I'E'$ each equal to ID; $K'F$ and $K'F'$ each equal to KC; $L'G$ and $L'G'$ each equal to LB, etc. The curve drawn through these points will be the side projection, or side elevation, of the curve of intersection.

DRAWING PLATE, TITLE: INTERSECTIONS AND DEVELOPMENTS

48. On this plate some dimensions are given in decimal fractions instead of common fractions. Such decimal dimensions should be laid off with a decimal scale, if the student has one. A decimal scale is a scale with inches divided into tenths, hundredths, etc. If the student has no decimal scale (and such a scale is not essential), he should take the nearest value of the decimal fraction in thirty-seconds of an inch.

To change a decimal fraction to a common fraction, having a desired denominator, multiply the decimal by the desired denominator of the common fraction, and express the result as a whole number, which whole number will be the numerator of the fraction.

Thus, to express $.765''$ in fourths, we have $.765 \times 4 = 3.06$ fourths = say, $\frac{3}{4}''$. To express $.765''$ in sixteenths, we have $.765 \times 16 = 12.24$ sixteenths = say, $\frac{12}{16}''$. To express $.765''$ in thirty-seconds, we have $.765 \times 32 = 24.48$ thirty-seconds = say, $\frac{24}{32}''$.

The length of the circumference of a circle = the diameter $\times$ 3.1416; hence,

The length of circumference of a circle whose diameter is

$$1\tfrac{3}{8}'' = 3.1416 \times 1\tfrac{3}{8}'' = 4.32'' = 4\tfrac{5}{16}''.$$

The length of circumference of a circle whose diameter is

$$1\tfrac{1}{2}'' = 3.1416 \times 1\tfrac{1}{2}'' = 4.71'' = 4\tfrac{23}{32}''.$$

The length of circumference of a circle whose diameter is

$$1\tfrac{1}{4}'' = 3.1416 \times 1\tfrac{1}{4}'' = 3.93'' = 3\tfrac{15}{16}''.$$

The length of circumference of a circle whose diameter is

$$1\tfrac{9}{16}'' = 3.1416 \times 1\tfrac{9}{16}'' = 4.9''.$$

$$4.9'' \div 2 = 2.45'' = 2\tfrac{7}{16}'' \text{ (see Fig. 10).}$$

49. This plate deals with the intersection of surfaces and their development. Fig. 1 shows the intersection of **two unequal cylindrical surfaces** whose axes $p\,q$ and $m\,n$ intersect at right angles. Their dimensions are given in the figure. For the sake of convenience, a bottom view is given, instead of a top view, as usual. First draw the front elevation, omitting, of course, the curve of intersection $E\,Q\,G\,D\,C\,B\,A$, which must be found. Then draw the side elevation and the bottom view, as shown. Divide the circle which represents the side projection of the cylindrical surface $F\,E\,A\,1$ into any convenient number of parts, in this case 12, and draw the projection lines $7\,E$, $6\,Q$, $5\,G$, $4\,D$, $3\,C$, $2\,B$, and $1\,A$ parallel to the axis $p\,q$. Also draw the projection lines 4–$4'$, 3–$3'$, 2–$2'$, 1–$1'$, etc. parallel to the axis $t\,v$. Choose a convenient point O, and through it draw two lines $O\,I$ and $O\,K$ parallel to the axes $p\,q$ and $m\,n$ of the cylinders. Continue the lines 4–$4'$, 3–$3'$, etc. downwards, until they cut $O\,I$ in 8, 7, 6, 5, etc. Now make $O\,8' = O\,8$, $O\,7' = O\,7$, etc.; this may be most conveniently done by taking O as a center, and describing arcs of circles with radii equal to $O\,8$, $O\,7$, $O\,6$, etc., cutting $O\,K$ in $8'$, $7'$, $6'$, etc. Through $8'$, $7'$, $6'$, etc., draw the lines $8'D'$, $7'C'$, $6'B'$, etc. parallel to the center line $r\,s$. Through the points D', C', B', and A', draw the lines $D'D$, $C'G$, and $B'Q$, parallel to the center line $m\,n$, and intersecting the lines $4\,D$, $5\,G$, $6\,Q$, $3\,C$, and $2\,B$ in the points D, G, Q, etc. The curve traced through these points will be the front elevation of the curve of intersection of the two cylindrical surfaces.

Fig. 2 shows the intersection of **two equal cylindrical surfaces** at right angles to each other, as in the case of a pipe elbow. When two cylinders having *equal diameters intersect, and their axes also intersect*, the front elevation of

the curve of intersection is always a straight line, no matter what angle the two axes make with each other.

Fig. 3 shows a symmetrical **three-jointed elbow** formed by the intersection of three cylindrical surfaces. The diameter of each of the three surfaces is $1\frac{1}{2}''$. The center lines of the surfaces $RAGS$ and $MNPH$ are to be at right angles to each other; then, in order that the arrangement shall be symmetrical, the center line of the third surface $AMHG$ must make an angle of 45° with the center lines of the other two.

To construct the elevation as shown in the figure, draw the two center lines mn and pq at right angles to each other; they intersect at 6. Lay off $6I = 1\frac{1}{2}''$ and draw an indefinite line RS through I perpendicular to mn. Make IR equal to $IS = 1\frac{1}{2} \times \frac{1}{2} = \frac{3}{4}''$, and draw RA and SG parallel to mn. Draw OK parallel to mn and $1\frac{1}{2}''$ below it. Through the point O, where RS and OK intersect, draw OT passing through 6, and bisect the angle ROT by the line OA, which intersects RA and SG in A and G. Lay off $6J = 2\frac{1}{4}''$ and draw PJN perpendicular to pq. Make $JP = JN = 1\frac{1}{2} \times \frac{1}{2} = \frac{3}{4}''$, and draw PH and NM parallel to pq. Draw OM so as to bisect the angle TOK; OM intersects PH and NM in H and M. Finally, draw AM and GH.

Fig. 4 shows the intersection of **two unequal cylindrical surfaces** whose axes intersect at an angle of 65° instead of 90°, as in Fig. 1. The method of finding the curve of intersection is in all respects similar to that used in Fig. 1, and, as the corresponding points have been given the same letters or figures, the directions given for Fig. 1 can be applied to Fig. 4 also.

Fig. 5 shows a **cylindrical piece of iron** $2\frac{3}{16}''$ in diameter that has been gradually turned down to $1\frac{5}{16}''$ diameter, and then having the larger part flattened on two sides. The large and small parts of the piece are connected by a graceful curve. The problem is to find the curve of intersection $A\,1\,2\,3\,B$ formed by the flattening. Draw the plan and front elevation from the dimensions given; also draw

the curve $C\,6'\,5'\,4'$, and its equal on the opposite side, so that they look to the eye about as seen in the drawing. In order that all the work sent to us may be alike, the radius of this curve and the position of the center have been given on the drawing. To locate the center, draw an indefinite horizontal straight line $1'' + 1\frac{1}{16}'' = 2\frac{1}{16}''$ above the base of the piece; and with C and D as centers, and a radius of $1\frac{1}{2}''$, describe short arcs cutting the line just drawn. The points of intersection will be the required centers. With O as a center, and radii of convenient lengths, as $O\,4$, $O\,5$, $O\,6$, etc., describe arcs cutting $A'\,B'$ in $3'$, $2'$, $1'$, etc. Through the points 4, 5, 6, etc. draw the lines 4–$4'$, 5–$5'$, 6–$6'$, etc., parallel to the center line $m\,n$, and intersecting the curve $C\,4'$ in $4'$, $5'$, $6'$, C, etc. Through the points A', $1'$, $2'$, etc. draw lines $A'A$, $1'$–1, $2'$–2, etc., parallel to $m\,n$, intersecting horizontal lines drawn through C, $6'$, $5'$, $4'$, etc., in A, 1, 2, 3, etc. The points A, 1, 2, 3, etc. are points on the required curve, and through them the curve may be drawn.

Fig. 6 is the **cylindrical surface** of one section of the elbow $1\,7\,A\,G$ of Fig. 2 rolled out into a flat plate; hence, if a flat plate were cut into the same shape and size as Fig. 6 and bent into a cylinder so that the ends $1\,G'$ and $1'G''$ touch each other, the vertical projection or front elevation would be the same as shown by $1\,7\,A\,G$ in Fig. 2. If a second plate were cut out in the same manner and bent into a circle, the two pieces on being brought together, as shown in Fig. 2, would touch at every point. The problem is to find the shape of the curve $G'\,A'\,G''$. The length of the line 1–$1'$ is evidently equal to the length of the circumference of a circle whose diameter is $1\frac{3}{8}''$, or $4.32''$, very nearly. Produce the line 1–7, Fig. 2, and make 1–$1'$ equal in length to $4.32''$. Divide the circle $1\,2\,3\ldots.12$ into a convenient number of equal parts, in this case 12, and erect the perpendiculars $1\,G$, $2\,F$, $3\,E$, etc., cutting the line of intersection $G\,A$ of the cylindrical surfaces in G, F, E, etc. Divide the line 1–$1'$ into the same number of equal parts that the circle was divided into, thus making the length 1–2 equal length of arc 1–2; 2–3, length of arc 2–3, etc. Through 1,

2, *3*, etc., draw the perpendiculars $1\,G'$, $2\,F'$, $3\,E'$, etc. and project the points G, F, E, etc. upon these perpendiculars, as shown, thus locating the points G', F', E', D', C', B', A' of the left-hand half of the required curve. The points on the right-hand half are found in the same manner, as shown, and the required curve can be drawn through these points.

50. A drawing like Fig. 6 is called the **development** of the cylindrical surface $1\,7\,A\,G$.

Fig. 7 is the **development of the cylindrical surface** $A\,G\,H\,M$ of Fig. 3. Make $1\text{–}1' = 1\frac{1}{2} \times 3.1416 = 4.71''$, nearly, and divide it into 12 equal parts to correspond with the 12 equal parts into which the dotted circle is divided. Project the points *6*, *5*, etc. of the dotted circle upon $O\,A$ as shown, thus locating the points B, C, etc. Through B, C, etc., draw $B\,6$, $C\,5$, etc., perpendicular to $O\,T$. Make $1\,G' = 1\,G''' = 1\,G$, $2\,F' = 2\,F''' = 2\,F$, $3\,E' = 3\,E''' = 3\,E$, etc. Through G', F', E', etc., trace the curve $G'\,F'\,E' \ldots .\,G''$, and, through G''', F''', E''', etc., trace the curve $G'''\,F'''\,E''' \ldots .\,G^{IV}$. Drawing $G'\,G'''$ and $G''\,G^{IV}$ completes the figure.

Fig. 8 is the development of the cylindrical surface $1\,F\,E\,A$, Fig. 1. The method used here is in all respects similar to the two preceding problems. In this case, the distances $1\,A$, $7\,E$, and $1'\,A'$ are all equal to $1\,A$ or $E\,F$, in Fig. 1; and $2\,B$, $6\,Q$, $8\,Q'$, and $12\,B'$ are all equal to $2\,B$ or $6\,Q$, in Fig. 1. The development of $L\,M\,P\,N$ is not given, for want of room, but the method will be explained in Fig. 10.

Fig. 9 is the development of the cylindrical surface $1\,F\,E\,A$, Fig. 4. The student should have no difficulty in drawing this, after having studied the preceding problems.

Fig. 10 is the development of the cylindrical surface $L\,M\,P\,N$, Fig. 4. Owing to the want of room, only that half of the development is shown which contains the part to be cut out. The length of a circle $1\frac{9}{16}''$ in diameter is 4.9″, nearly; half of this is 2.45″. Hence, the line $Y'\,Y''$, Fig. 10, which equals the length of the semicircle $Y'A'\,Y''$, Fig. 4, is 2.45″ long. The distance $X'\,Y' = X''\,Y''$ equals the length of the cylinder, $L\,N$ or $M\,P$. Lay off $X'S$ equal

to the length of the arc $Y'D'$; SR equal to the arc $D'C'$; RN equal to the arc $C'B'$; NM equal to the arc $B'A'$, etc. Find the lengths of these arcs by means of the method given in connection with Fig. 54. Draw through these points the perpendiculars SS', RR', etc. With the spacing dividers, set off SD_1 equal to SD in Fig. 4; RG_1 equal to RG; NQ_1 equal to NQ; and ME_1 equal to ME. Also, $R'C_1$ equal to $R'C$; $N'B_1$ equal to $N'B$; and $M'A_1$ equal to PA. In exactly the same manner, find the points on the right-hand half of the curve. If a plate were cut of the same size and shape as shown in Fig. 10, and rolled into a semicylindrical surface, the diameter of which is $1\frac{9}{16}''$, it would exactly fit the plate cut like Fig. 9 rolled into a cylindrical surface, the diameter of which is $1\frac{1}{4}''$, the two being placed together as shown in Fig. 4.

Fig. 11 shows a **conical surface cut by a plane,** and Fig. 12 shows its **development.** Draw the elevation and horizontal projection of the base as shown in Fig. 11. Divide the projected circle (base of cone) into a convenient number of equal parts, in this case 12, and project the points *1*, *2*, *3*, etc. on the base *1'–7'*, thus locating the points *1'*, *2'*, *3'*, etc. Join these points with the apex O of the cone, by the lines $O\,1'$, $O\,2'$, $O\,3'$, etc., cutting the plane in A, B, C, etc. Now, choose a convenient point O, Fig. 12, and with this as a center, and a radius equal to $O\,1'$, or $O\,7'$, Fig. 11, the slant height of the cone, describe an arc *1–1'* of a circle. Make the *length of this arc* equal to the length of the circumference of a circle having the same diameter as the base of the cone. This may be conveniently done as follows: length of arc $= 2 \times 3.1416 = 6.28''$, nearly. Draw a straight line 6.28″ long and divide it into, say, 4 equal parts. Describe an arc having a radius equal to $O\,1'$, the slant height of the cone, and find the length of a part of this arc equal to $6.28 \div 4 = 1.57''$ by means of the method described in connection with Fig. 53. With the dividers set for the chord of the arc just found, space off the chord four times on the longer arc *1 2 3 . . . . 1'*, Fig. 12. Divide the arc into the same

number of equal parts that the circle *1 2 3. . . . 12* has been divided into, that is, 12 parts. Join the points of division *1, 2, 3*, etc. with the center *O* by the lines *O 1, O 2, O 3*, etc., as shown. Project the points *B*, *C*, *D*, etc., Fig. 11, upon *O 1′*, in B_1, C_1, D_1, etc., as shown, and lay off *O A* equal to *O A′* equal to *O A*, Fig. 11; *O B* equal to *O B′* equal to $O B_1$; *O C* equal to *O C′* equal to $O C_1$, etc., and through these points draw the curve. A plate cut of the same size and shape as shown by *A G A′ 1′ 7 1* can be bent into the conical surface shown by the elevation *A G 7′ 1′*.

Particular attention must be given to the method explained above for laying out the curve of the development in Fig. 12. It would be entirely wrong to take the measurements from the lines *O F*, *O E*, *O D*, *O C*, etc., Fig. 11. The reason for this is that these lines, being on the surface of the cone, are inclined towards the observer, and so do not appear in their true lengths. The line *O D*, for example, if measured on the surface of the cone itself, would evidently be of the same length as the line $O D_1$; but in the figure it is much shorter. The line $O D_1$, however, appears in its true length in the figure, because it is not inclined to the observer in the position shown. The actual distance of point *D* from the apex *O*, therefore, is $O D_1$, which is the distance to be laid off for point *D* in the development. The same holds true for the other points.

SHADE LINES

51. The use of the heavy shade line will now be explained. In Fig. 71, by means of the shade lines, the draftsman knows, without looking at any other view of the object, that the rectangles *1* and *4* represent square holes, and *2* and *3*, square bosses. When he looks at the other view, it is to find the depth of the holes and the height of the bosses. This explains the use of the shade lines, viz.: to show, from that view of the drawing which is being examined, whether the part looked at is above or below the plane of the surface; that is, for example, whether

the rectangles *1*, *2*, *3*, and *4* are the tops of bosses or bottoms of holes, and, consequently, whether they extend above or below the surface of $ABDC$. In order that the shading may be uniform on all drawings, the light is assumed to come in one invariable direction, in such a manner as to be parallel to the plane of the paper, to make an angle of 45° with all horizontal and vertical lines of the drawing, and to come from the upper left-hand corner of the drawing. Each view of the object represented is shaded independently of any of the others; and, when shading, the object is always supposed to stand in such a position that the drawing will represent a top view. Any surface that can be touched by drawing a series of parallel straight lines, making an angle of 45° with the horizontal and vertical lines of the drawing, is called a **light surface**; a surface that cannot be touched by lines having this angle is called a **dark surface.** All of the edges caused by the intersection of a light and dark surface, or two dark surfaces, are usually shaded; that is, the edges thus formed are drawn in heavy lines. Exceptions to this rule are sometimes made by experienced draftsmen, when a rigid adherence to it will produce a bad effect or will render the drawing ambiguous.

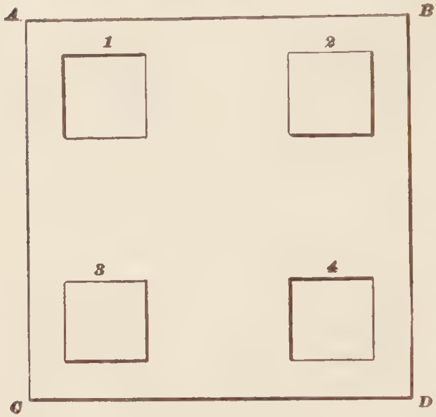


FIG. 71

Fig. 72 shows a plan of a series of triangular wedges radiating from the common center O. The top is, of course, a light surface, and, in order to determine whether the perpendicular surfaces are light or not, the 45° triangle may be used. Take the wedge ROA. A line drawn at an angle of

45°, the direction of the arrows, would strike the side of which OA is the edge; hence, this side is a light surface, and the top being also a light surface, the line OA must be light. OR, on the contrary, is a heavy line, since the light cannot strike the side of which OR is the edge without passing through the wedge. Hence, this is a dark surface, and its intersection OR with the light surface OAR requires a shaded line. For the same reason, AR is also shaded. The same reasoning as

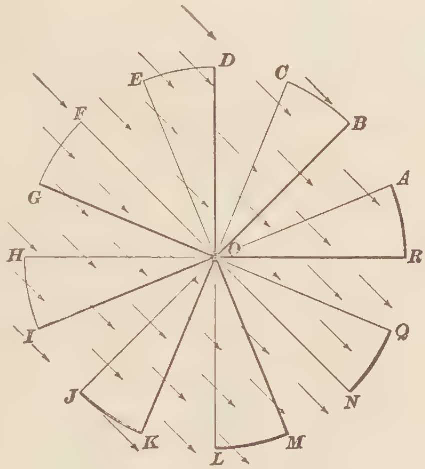


FIG. 72

the above applies to the lines OB, OD, OG, OI, OK, and OM; also, to QN, ML, and KJ. CB is not shaded, because the light strikes the surface of which CB is the edge, as shown by the arrow, making CB the intersection of two light surfaces. ON makes an angle of exactly 45° with the horizontal, and is treated as if it were the edge of a light surface; this is done in every case in which the line considered makes an angle of 45° with the horizontal.

In shading holes, or any parts of the drawing denoting depressions below the surface under consideration, a slightly different assumption is made. Fig. 73 shows the plan of a square block with a hexagonal hole in the center. If the light passed over the surface $ABCD$, parallel to the plane of the paper as previously assumed, all the inside surfaces would be dark, and the entire outline of the hexagon $EFGHIK$ would be shaded. In order to prevent this and make the work similar to that which has preceded, the rays of light are assumed to make an angle of 45° with the plane of the paper when shading holes and

depressions. Hence, the light will strike the surfaces whose edges are GH, HI, and IK, as shown by the arrows, leaving the surfaces whose edges are KE, EF, and FG dark as before. Therefore, these latter edges will be shaded, and the edges GH, HI, and IK will be light. See also Fig. 71.

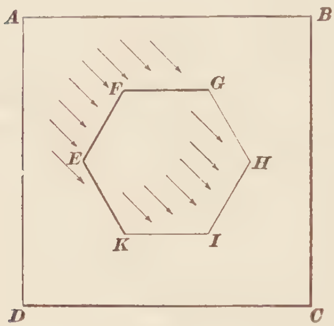


FIG. 73

The conventional method of shading circles which represent the projections of cylinders, or circular holes, is as follows: AB, Fig. 74, is the projection or end view of a cylinder having for a base the circular area AB. Draw the arrows EA and FB, making angles of 45° with the horizontal diameter, and tangent to the circle at A and B. That half of the circle in front of these two points of tangency is to be shaded, and, in order to make the drawing look well, the center point for the compasses is shifted along the line CH parallel to EA and FB in the direction of the arrow an amount equal to the thickness of the desired line. With the same radius that was used to describe the original circle, describe part of another circle, being careful not to run over the first circle, and stopping when the two lines coincide. The directions for shading a hole are precisely the same as for the projection of a cylinder base, except that the half BCA of the circle in Fig. 75 is to be shaded, the center being shifted as before, but in the opposite direction, as shown by the arrow.

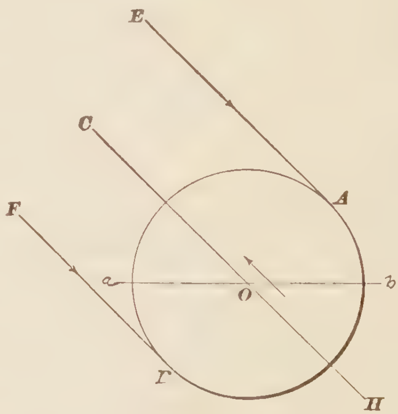


FIG. 74

Vertical projections of cylinders are shaded as shown in the front elevation of Fig. 5, Drawing Plate, title: Projections—I.

After studying the foregoing concerning shade lines, the student should be able to see the reason for the using or omitting of any shade lines on the drawings in the following plates. In the case of an object like the hexagonal prism in Fig. 6, Drawing Plate, title: Projections—I, no part of the upper base or line *Se* is shaded, although, strictly speaking, the part *c e* of the line should be shaded; but, as this would make part of the straight line *Se* heavy and the greater part light, the whole line is drawn light. This is one of the exceptions previously mentioned.

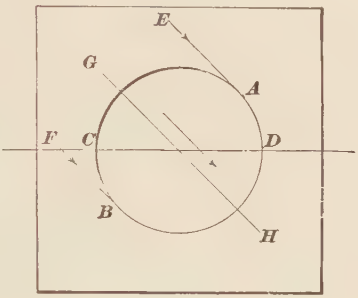


Fig. 75

MECHANICAL DRAWING

CENTER LINES

1. Fig. 1 represents a thick wedge having a cylindrical hole running through its entire length. The lines *mn*, *pq*, and *rs* are called **center lines.** Center lines are usually drawn through the center of anything that is round, such as a cylinder or a cylindrical hole. In the case of a circle, there are usually two center lines, one being at right angles to the other, as shown in view *B*, Fig. 1. By drawing two center lines through a circle in the manner just mentioned, the center of the circle is located by their intersection. The mere presence of these lines shows in most cases that part of the object through which they are drawn is *round*. It is very seldom that center lines appear on drawings unless they are the center lines of cylindrical surfaces. They may sometimes be drawn to indicate that the surface is a regularly curved surface, such as would be formed by circular arcs, or

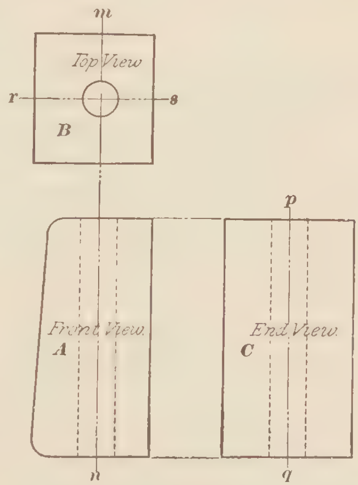


FIG. 1

one having the shape of an ellipse. In very rare cases, for some special reason, a line that corresponds to a center line may be drawn for some particular purpose, but such a line is not, in the strict sense of the word, a center line.

2. Center lines are an extremely important feature of a drawing, since the workman is guided by them in doing the work called for by the drawing. For instance, suppose that it was required to make a wedge like that shown in Fig. 1, and that the workman was given a piece of cast iron having approximately the shape indicated by the drawing. Suppose, further, that it was necessary to have the hole located exactly as shown in the drawing with reference to the sides of the wedge, and that the sides and ends of the wedge were all to be "finished." The first thing that the workman would probably do would be to drill the hole, and, if the job had to be very accurate, he would drill the hole a little smaller than the drawing calls for and then ream it out to size. He would then face the ends square with the center line of the hole and make the length of the wedge the same as shown on the drawing. The sides of the wedge would then be planed and finally finished with a file, the workman working all the time from the center line mn. If the drawing shown in Fig. 1 is intended to be worked to, it would, in most shops, be supplied with proper dimensions.

SECTIONS AND SECTION LINING

3. In order to show the interior of hollow objects, they are often drawn in section, and the kind of material is then usually indicated by certain combinations of lines. Unfortunately, there is no universally adopted standard; thus, a certain combination of lines may indicate that the material is cast iron if drawn in one office; in another office this same combination may have been adopted to represent brass, and so on. As far as working drawings are concerned, there is usually no difficulty experienced on account of this diversity of practice, since as a general rule the material is, and should always be, distinctly specified on the

drawing in order to prevent any mistake on the part of the workman.

4. The most commonly used combination of lines for different materials is shown in Fig. 2. Steel of all kinds is

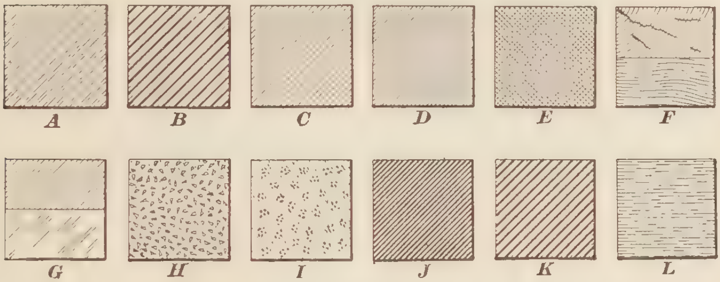


FIG. 2

indicated as shown in view *A*; view *B* shows the style of sectioning employed for wrought iron. Cast iron is usually sectioned as shown at *C*; brass and other similar copper alloys are sectioned in the manner shown at *D*. For lead, Babbitt, and similar soft metal, the sectioning shown at *E* is extensively used. Wood, when cut across the grain, is usually sectioned as shown in the upper half of view *F*, and when cut along the grain, as shown in the lower half. Wood is also frequently indicated on a drawing by section lines, even when it is not a section. Glass and stone, when in section, are often indicated in the manner shown by the upper half of view *G*; when not in section, they are frequently drawn as shown in the lower half of that view. Concrete may be indicated as in view *H*; view *I* gives a common representation of leather. Rubber and wood fiber are sectioned as in view *J*, firebrick as in *K*, and water as in *L*.

5. Instead of representing sections by lines, they are occasionally colored, the colors used indicating the different materials. While this practice is very common in Europe, it is very rarely found in the United States.

6. Sections of material that appear too thin on a drawing to be conveniently sectioned, or when it is desired to make the section very prominent, are often blackened in, as shown in Fig. 3. In order to separate different pieces, a white line is then usually left between them. Black sections are most frequently employed for sectional views of structures composed of plates and rolled sections, such as **I** beams, angle irons, bulb angles, rails, **Z** bars.

FIG. 3

7. On many sectional views, it will be noticed that the section lines do not run in the same direction. This invariably means that there is more than one piece in the section given. Thus, referring to Fig. 4, it will be seen that the section lining shown at *b*, *b* is at a right angle to the other section lining. It is the general rule among draftsmen that all parts of the same piece shown in section must be section-lined in the same direction, irrespective of the continuity of the section. Thus, referring again to Fig. 4, the fact that all section lining marked *A* is in the same direction immediately establishes the fact that this part of the view is a section of the same piece. Likewise, since the sectioning shown at *b*, *b* runs in the same direction, it follows that *b*, *b* are sectional views of one piece, which is separate from *A*.

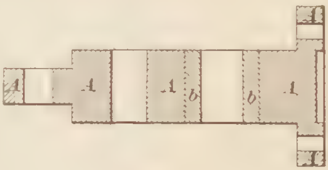


FIG. 4

8. The above rule governing the direction of section lines is always adhered to when possible; when any departure is necessary, care is taken to prevent ambiguity. Where only the sectional view is given, it is often very difficult to understand the drawing, and sometimes a violation of the

above rule will cause an erroneous conclusion to be drawn. Referring to Fig. 5 (*a*), cover up the front view shown at (*b*). Then, since the sectioning of *A* and *B*, and also that shown

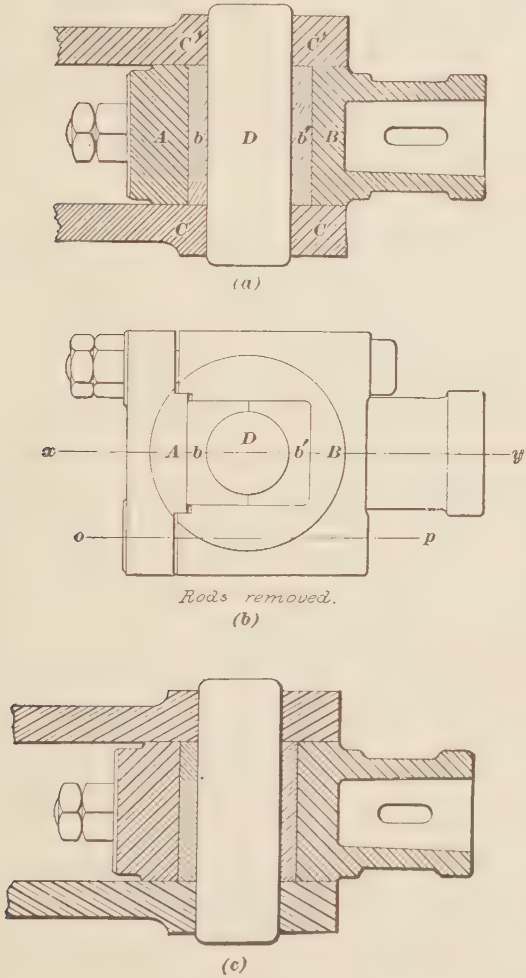


FIG. 5

at *b* and *b*′, are respectively in the same direction, any one would be perfectly justified in assuming that *A* and *B* was a sectional view of a rod fitted with a solid bushing *b*.

Furthermore, since C, C and C', C' are sectioned the same way, the conclusion that they were the jaws of a forked rod would be justifiable. Referring now to view (b), it is seen that b and b' are separate brass boxes; the part B is seen to be separate from the cap A, and the note "*Rods removed*" indicates that C is separate from C'. The way the sectional view should have been section-lined to correspond to the front view shown at (b) is given in Fig. 5 (c).

9. When a cutting plane passes through the axis of a shaft, bolt, rod, or any other solid piece having a curved surface and located in the plane on which the section is taken, it is the general practice not to show such solid pieces in section, but in full. Thus, in Fig. 5 the sectional view is taken on the plane represented by the line $x\,y$, which passes through the axis of the pin D. This pin is shown in full, however. The practice here shown is rarely departed from by experienced draftsmen, since it makes a drawing easier to read and also saves considerable time in making the drawing.

10. Fig. 5 also shows another feature that is frequently met with in shop drawings. Referring to the illustration, it is seen that no bolt is shown in the lower half of the object, as far as the front view (b) is concerned. A center line $o\,p$ is drawn in, however; this center line indicates to the workman, who reasons from the symmetry of the object in respect to the center line $x\,y$, that the lower half of the object is to be supplied with a bolt placed in the plane given by the center line $o\,p$. In case of symmetrical work, draftsmen will frequently complete only one half of the view and merely indicate the other half by a few lines or not at all, trusting to the judgment of the workman for a correct reading of the drawing. In the best practice, a note is made on the drawing calling attention to the fact that the indicated portion of the view is a duplicate of the complete portion.

BREAKS

11. When a long and comparatively slender object is to be drawn, it often happens that, when drawn to a sufficiently large scale to make it intelligible, it will extend beyond the space available. In such a case, part of the object is broken out and the remaining ends are pushed together. The fact that part of the object is broken away for the sake of convenience is indicated by a so-called **break.** It is always understood that the part broken away and not shown is of the same size and shape as the parts contiguous to the break. In some cases, one end of the object is broken away.

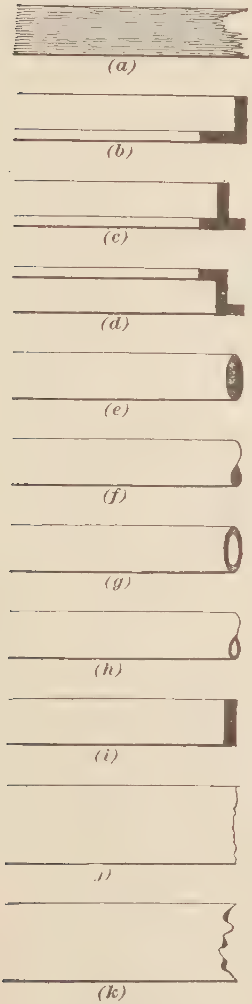
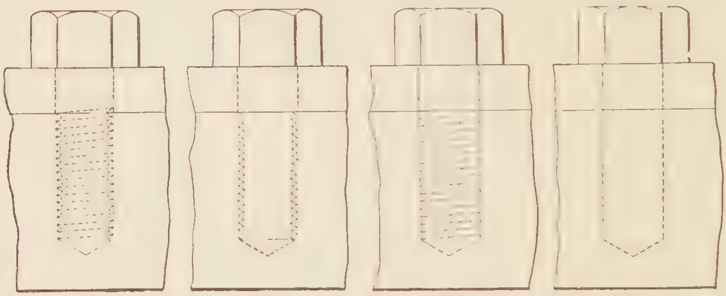


FIG. 6

12. Breaks may be indicated in various ways; most commonly, the break is given an outline that will reveal the shape of the object. Conventional methods of indicating breaks are shown in Fig. 6. Wood is usually shown broken in the manner illustrated at (*a*), angle irons as at (*b*), T irons as at (*c*), Z bars as at (*d*). Cylindrical objects are occasionally broken as shown at (*e*), but most frequently in the manner shown at (*f*). Pipes and similar hollow cylindrical objects may be broken as shown at (*g*); but, more frequently, the break is made as shown at (*h*). Rectangular objects may be broken in the manner shown at (*i*); plates and objects other than those included between views (*a*) and (*i*) are often shown broken off by drawing a wavy freehand line as in (*j*) and (*k*).

HIDDEN SCREW THREADS

13. When the screw thread is hidden by part of the object and it is deemed necessary to show it in dotted lines, it is usually drawn in one of the four ways illustrated in Fig. 7. Of these the method shown in Fig. 7 (*a*) is probably



(*a*) (*b*) (*c*) (*d*)

FIG. 7

the clearest; that shown in Fig. 7 (*b*) is fairly good; and the one shown in Fig. 7 (*c*) is cheap. The method illustrated in Fig. 7 (*d*) is practically no representation of a screw thread at all; if used it usually must be supplemented by a note such as "$\frac{3}{4}''$ *stud*," or "$1\frac{1}{8}''$ *bolt*," and so on.

REPEATED PARTS OF OBJECTS

14. When an object has a relatively large number of similar component parts, they are rarely all shown on a working drawing. Usually, a few of them are shown in full and the rest are merely indicated by showing the position of the center of each part. Sometimes even this is not done, but a note is placed on the drawing calling attention to the fact that some certain part of the object is to be repeated.

15. Fig. 8 is an example of how repeated parts of an object may be treated. Referring to the illustration, which is a top view of a pipe flange, Fig. 8 (*a*) shows three bolts drawn in. The position of the rest of the bolts is indicated by the short radial lines drawn across the bolt circle. In

Fig. 8 (*b*), the bolt circle is drawn in and a note is written along it that is sufficiently definite to convey the idea to the

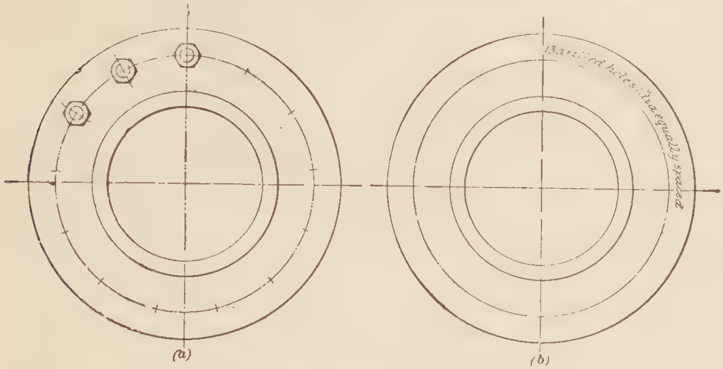


FIG. 8

mind of the workman. This latter method is most commonly used on working drawings.

16. When making a drawing of a gear-wheel, especially when it is a working drawing, it is customary to draw in only two or three teeth and specify how many teeth the wheel is to have. This answers the purpose as well as if all the teeth were drawn and has the advantage that an enormous amount of time is saved in making the drawing. Likewise, in drawings of objects built up of plates or rolled sections, as in boiler and bridge drawings and similar work, only a few rivets, or staybolts, or similar repeated parts are usually shown, and the location of the rest is indicated by showing the position of their centers or by a suitable note placed on the drawing.

ABBREVIATIONS USED ON DRAWINGS

17. The most commonly used abbreviations are *D.*, *Dia.*, *Diam.*, *d.*, *dia.*, and *diam.* for "diameter," and *R.*, *Rad.*, *r.*, and *rad.* for "radius." "Wrought iron" is usually abbreviated to *Wr't Iron.* The abbreviation *Thds.* or *thds.*, with a number prefixed, stands for "threads per inch"; thus, *14 thds.* means "make 14 threads per inch." The word *tap*,

with a number prefixed, always means that a hole is to be finished by tapping it with a tap of standard proportions, having the diameter given by the prefixed number. When a tap other than a standard tap is to be used, it is distinctly specified. *Drill* is always taken to mean that a hole is to be put through the object by drilling. *Bored* or *Bore* means "finish a hole by boring it." *Planed* is always understood to mean "this surface is to be finished by planing." *Cored* implies that the hole to which it is applied is to be cored out and left that way; that is, it is not to be finished by machining. *Faced* almost invariably implies that the surface to which it is applied is to be machined square with a hole in the object. *Turned* is an abbreviation for "finish by turning." *Scraped* implies that a surface is to be finished by scraping. *Tool finish* means that the surface, after machining, is not to be finished any further. *Black*, on objects formed by forging, implies that the part to which it is applied is to be left as it comes from the smith. The term *Ream* or *Reamed* means that a hole is to be finished by reaming; when applied to a bolt, it is understood that the bolt is to be fitted to a hole that has been previously reamed. The terms *Shrinking Fit*, *Forcing Fit*, and *Driving Fit* written behind a dimension always imply that, in machining the part, the workman is to make the allowance necessary for the kind of fit called for. The fact that part of an object is to be finished by machining, filing, or grinding is often indicated by marking the outlines with an *f* written across or near it, or writing *fin.* along it. In some cases, draftsmen will draw a dotted line or a full red line at a little distance from the outline and write *f* across it; it is usually understood, in that case, that the lengths of the supplementary lines denote the extent of the surfaces that are to be finished.

KINDS OF WORKING DRAWINGS

18. Working drawings are divided into two general classes, which are: *assembly*, or *general*, *drawings*, and *detail drawings*.

Assembly, or **general, drawings** show the workman the relation between, and the places or positions occupied by, the different component parts of a structure, machine, device, fixture, implement, etc. If any dimensions are given, they are usually only leading dimensions.

Detail drawings show the exact shape and size of each integral part. For this purpose they are supplied with all the dimensions required by the workman and any additional explanatory notes that the draftsman may consider necessary.

Detail drawings may be made so complete that they will answer for the patternmaker, blacksmith, and machinist, and they are usually so made in the smaller shops. In the large shops, however, separate drawings are often made for the patternmaker, blacksmith, and machinist; the detail drawing for the use of the patternmaker, then, contains only the dimensions and notes needed by him to make the pattern; that for the blacksmith contains the dimensions needed for making the forging; and, finally, that for the machinist contains all dimensions needed by him.

19. Attention is called to the fact that practice varies somewhat in different places in regard to the dimensions given on detail drawings, at least as far as drawings for the patternmaker and blacksmith are concerned. In some places, the dimensions given represent the size the object is to be when *finished;* hence, the blacksmith or patternmaker must make necessary finishing allowances himself. In other places, again, the finishing allowance has been, and usually is, made by the draftsman; the dimensions given are then those of the pattern or forging. If in doubt about the practice followed in a particular drawing office, it is a good plan to find out by inquiry what system is used in the shop under consideration. In the best modern practice, a note calling attention to the fact that the sizes given are those when finished is placed on the drawing; thus, "*All finished sizes*" or some similar note.

FIG. 9

SCALES

20. When it is desired to make a drawing other than full size, special scales are used. Thus, suppose it is required to make the drawing $\frac{1}{4}$ size; then, 3 inches on the drawing would represent 1 foot on the object. Hence, if 3 inches are laid off and divided into 12 equal parts, each of these parts will represent 1 inch on the object. If these parts be subdivided into 2, 4, 8, etc. parts, each will represent $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, etc. of 1 inch on the object. A scale of this kind is called a **quarter scale,** or a **scale of 3 inches to the foot.** An **eighth scale,** or a **scale of $1\frac{1}{2}$ inches to the foot,** would be constructed in the same way, except that $1\frac{1}{2}$ inches would be laid off instead of 3 inches. These scales are written $3'' = 1$ ft., $1\frac{1}{2}'' = 1$ ft.

21. Fig. 9 shows a scale which is convenient for the student, inasmuch as it combines eleven different systems of subdivision and may be used for all the work ordinarily done in a drafting room. This scale is triangular in section and 12 inches in length, and on each of its edges is laid off a scale, as shown at A, B, and G. The scale at G is "full size"; that is, this edge of the scale is divided into inches and fractions of an inch down to sixteenths, and is used for drawings in which an object is represented in its natural size. On its opposite side, at B, is shown the quarter-sized scale of $3'' = 1$ ft. The first 3-inch (actual size) division, from B to C, is subdivided into 12 parts representing inches, and each inch is then divided into proportional fractions of an inch, generally eighths. From C to D, D to E, and E to F, the scale is marked

in its main divisions of 1 foot each, each foot being 3 inches long, actual size. From *A* to *B* the scale is independently divided into spaces of $1\frac{1}{2}$ inches (actual size) to form an eighth-sized scale, or $1\frac{1}{2}'' = 1$ ft., the divisions of the latter occurring on and between the marks for the 3-inch scale.

The other sides and edges of the instrument are divided into scales of 1 inch and $\frac{1}{2}$ inch, $\frac{3}{4}$ inch and $\frac{3}{8}$ inch, $\frac{1}{4}$ inch and $\frac{1}{8}$ inch, and $\frac{3}{16}$ inch and $\frac{3}{32}$ inch to the foot. Different makers do not always arrange their scales in the same manner. Thus, instead of having a full-size scale and scales of $3'' = 1$ ft. and $1\frac{1}{2}'' = 1$ ft. on one side, as shown in Fig. 9, some makers have the full-size scale and $\frac{3}{16}'' = 1$ ft. and $\frac{3}{32}'' = 1$ ft. on one side. It will be observed that the numbering of the feet on these scales does not start at the end of the instrument, but at the first division from the end. Thus, on the quarter-sized scale the zero mark is placed at *C* and the first foot is measured to *D*. This is done so that the feet and inches may be laid off independently and with one reading of the scale.

The figures indicating the number of feet on this scale are placed along the extreme upper edge at *D*, *E*, and *F*, the numbers running in a direction away from the part containing the inches. The numbers indicating inches run in an opposite direction from those defining the feet.

To lay off 2 feet $3\frac{3}{4}$ inches on a scale of $3'' = 1$ ft. and from a given point, place the scale on the point so that the 2-foot mark will be directly over it; then from the zero mark *C* lay off $3\frac{3}{4}$ inches, as shown, locating a second point. The length of the distance thus laid off between the two points represents 2 feet $3\frac{3}{4}$ inches. The scale of $1\frac{1}{2}'' = 1$ ft. is used in a similar manner to lay off the same distance. The figures indicating feet on this scale are placed nearer the edge, in order to prevent confusion in reading.

To draw to half size, or 6 inches to the foot, use the full-size scale, and remember that every $\frac{1}{2}$ inch on that scale

corresponds to 1 inch on the object, that is, that every dimension is only half of the real length. To lay off $5\frac{7}{8}$ inches, lay off 5 half inches and $\frac{7}{16}$ of an inch over; the result is a line $5\frac{7}{8}$ inches long to a scale of 6 inches to the foot.

If it is desired to draw to a scale of $\frac{3}{4}$ of an inch to the foot, or $\frac{1}{16}$ size, the scale of $1\frac{1}{2}$ inches to the foot may be used if the draftsman has no scale of $\frac{3}{4}'' = 1$ ft., halving all dimensions, as in the previous case of drawing to a scale of 6 inches to the foot with a full-size scale. It sometimes happens that a draftsman is obliged to make a scale, when the size of his plate is limited and a general drawing of some object is desired. By *general* drawing is meant a complete view of the object in plan and also one or two elevations. In such a case, one scale may be too large to enable the drawing to be made on a sheet of the required size; another

FIG. 10

scale may make it too small to show up well. For example, a $\frac{1}{8}$ scale may be too large and a $\frac{1}{16}$ scale too small; a $\frac{1}{12}$ scale may be just right. If the draftsman has no $\frac{1}{12}$ scale (that is, a scale of 1 inch to the foot), he may make one by taking a piece of heavy drawing paper and cutting out a strip about the size of an ordinary scale and laying off the inch divisions on it. Each division or part will represent 1 foot on the object. Divide one of the end parts into 12 equal parts and each will represent 1 inch on the object. Lines indicating half and quarter inches may be drawn if considered necessary.

Fig. 10 shows part of a scale made in this manner, giving feet, inches, and half inches—the quarters, eighths, etc. of an inch being judged by the eye.

CONVENTIONAL REPRESENTATION OF A NUT

22. Fig. 11 shows the ordinary conventional method of representing a nut. The bottom of the thread is $1\frac{1}{2}$ inches in diameter and is represented by the dotted circle; this shows that it is intended for a screw $1\frac{1}{2}$ inches in diameter. The height of the nut equals the diameter of the bolt or screw on which the thread is cut. The two views on the center line *m n* should be drawn without difficulty. To draw the curves *e a* and *a d*, project *b* and *c* at right angles

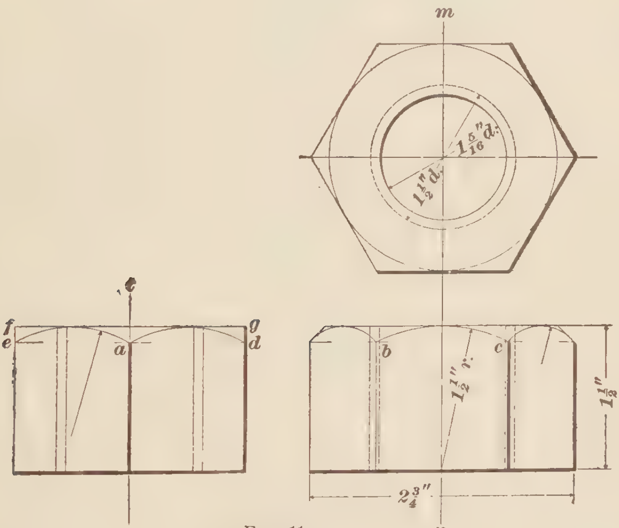


FIG. 11

to *t v* in the points *d*, *a*, and *e*; pass arcs of circles through *e* and *a* and through *d* and *a* tangent to *f g*, finding the centers of these arcs by trial. The best way of doing this is to draw lines parallel to *t v* midway between *e a* and between *a* and *d*. Then, by trial with the compasses, find a center on these lines such that an arc struck with the compasses from this center will pass through *e* and *a* (or *a* and *d*) and be tangent to *f g*. In the right-hand view, the radius of the arc *b c* is the same as the height of the nut; the centers of the other two arcs are found by trial in the manner just described.

DRAWING PLATE, TITLE: DETAILS

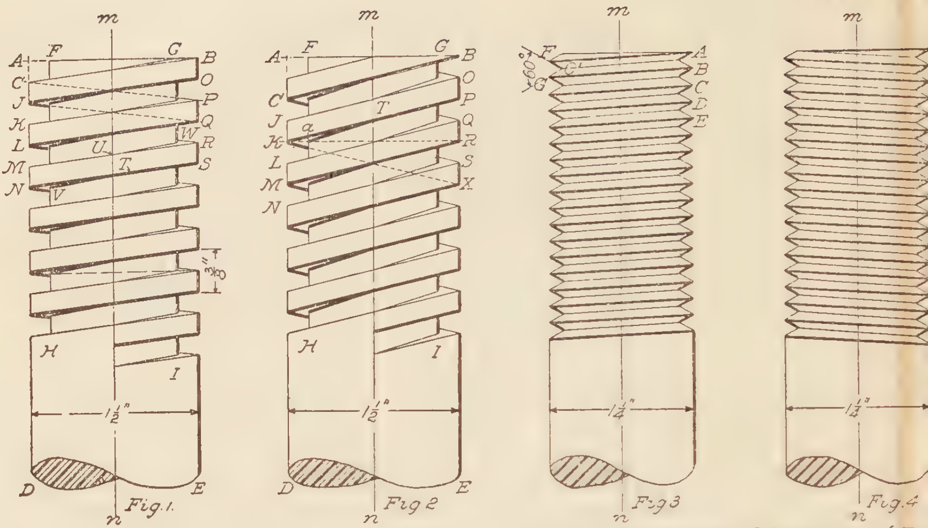
23. The first eight figures of this plate show the conventional methods of representing screws. The actual projection of a screw thread will be similar to the projection of a helix; but in order to save the time required to locate the points and trace in the curves, the following methods are universally used, except, perhaps, in the case of screws of very large diameter and pitch, drawn full size.

24. Fig. 1 represents a **single square-threaded screw** $1\frac{1}{2}$ inches in diameter and $\frac{3}{8}$ inch pitch. To draw the screw, first draw the center line $m\,n$ and a line $A\,B$ at right angles to it. Make the distance $A\,B$ equal to the diameter of the screw, or $1\frac{1}{2}$ inches, and through the points A and B draw lines $A\,D$ and $B\,E$ parallel to the center line $m\,n$. Also lay off on the line $A\,B$ distances $A\,F$ and $B\,G$ equal to one-half of the pitch, and through the points F and G draw lines $F\,H$ and $G\,I$ parallel to the center line $m\,n$. These lines show the depth of the thread. On the line $A\,D$ lay off the width of the thread and of the groove, $A\,C$, $C\,J$, $J\,K$, etc., each equal to one-half of the pitch, or $\frac{3}{8} \times \frac{1}{2} = \frac{3}{16}$ inch. Draw the line $B\,C$, and through the points J, K, L, M, etc., draw lines parallel to $B\,C$. Draw faint pencil lines through the points C and P, J and Q, K and R, etc. to represent the back edges of the threads, and make the parts that are seen full lines; then draw the lines $T\,V$, $U\,W$, etc. The method of drawing the remainder of the screw and the reason for using the heavy shade lines, as shown, should be apparent without further explanation.

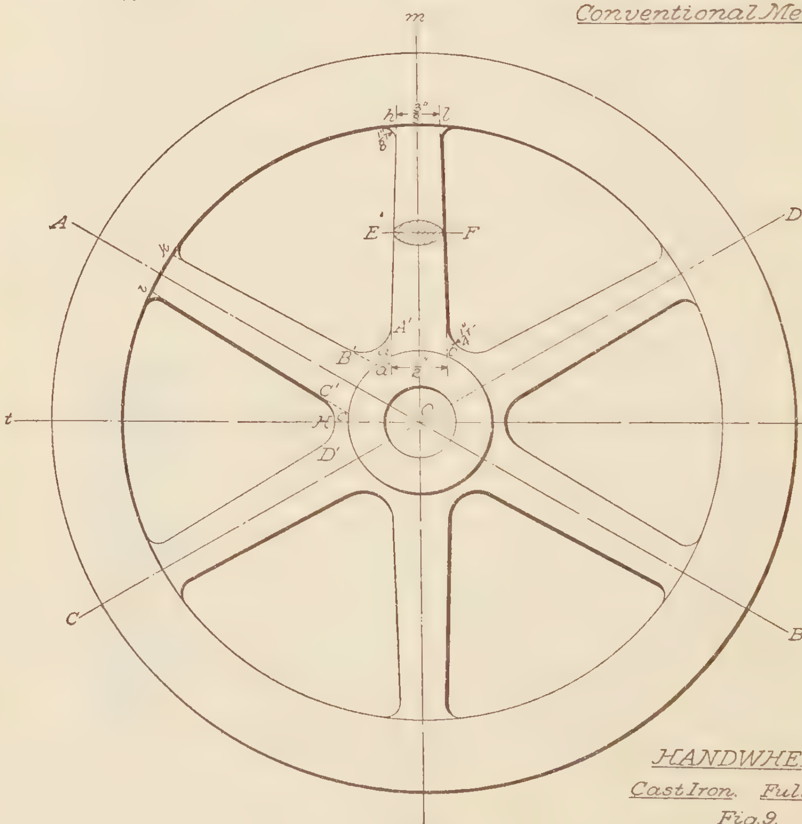

FIG. 12

It will be noticed that the width of the thread and of the groove, measured parallel to the center line $m\,n$, and the depth of the thread are all exactly the same; that is, they are each equal to one-half of the pitch. If a section were taken through the center line $m\,n$, the thread and groove would look like Fig. 12, a series of squares, hence the term *square thread.*

DETA



Conventional Methods of Re



HANDWHEEL.

Cast Iron. Full Size.

Fig.9.

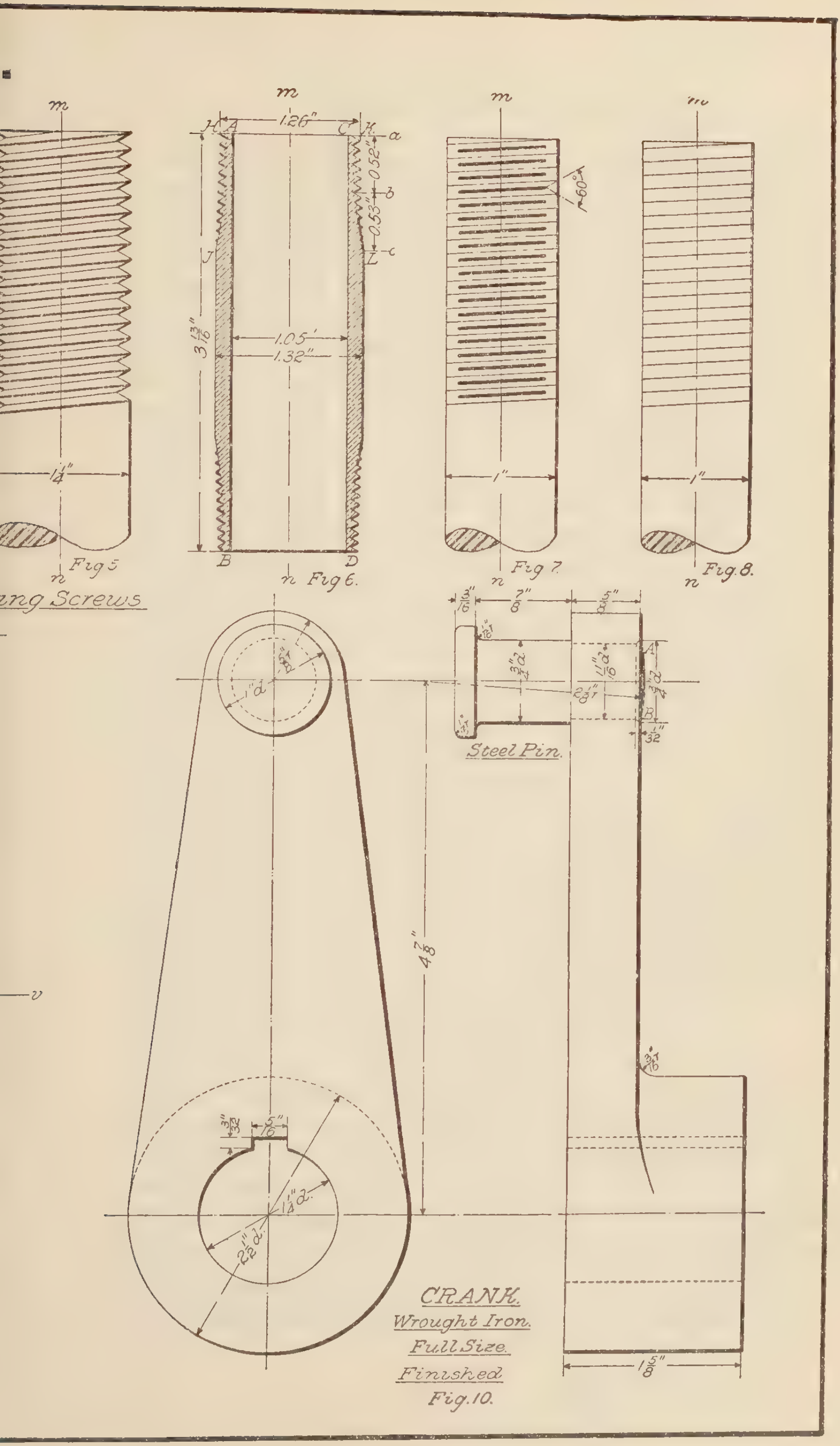


Fig 5
ang Screws
1.26"
0.52"
0.53"
1.05"
1.32"
Fig 6.
Fig 7.
60°
Fig. 8.
1"
Steel Pin.
CRANK.
Wrought Iron.
Full Size.
Finished
Fig. 10.

25. Fig. 2 shows a **double square-threaded screw** $1\frac{1}{2}$ inches in diameter and with $\frac{3}{4}$ of an inch pitch. The reason for using a double thread is that if the single square thread were used, the depth would be so great as to weaken the bolt or rod on which it was cut and render it unsafe for the purpose for which it was intended. To prevent this, either the diameter of the rod must be increased or the thread must be cut of the same depth and thickness as a thread of half the pitch, or, in this case, as if the pitch were $\frac{3}{4} \times \frac{1}{2} = \frac{3}{8}$ of an inch, as in the preceding problem; another thread of the same size and pitch ($\frac{3}{4}$ of an inch) must be cut half way between these first threads, thus giving a double thread. The pitch, or distance that the screw would advance in one turn, would be $\frac{3}{4}$ of an inch, the same as if it were a single-threaded screw of $\frac{3}{4}$ of an inch pitch, while the depth of the thread is only half as great. To draw it, proceed exactly as in the last figure. To get the direction of the line BC, which in this figure represents the projection of the bottom edge of the top of the thread, lay off AC equal to one-half of the pitch, or $\frac{3}{4} \times \frac{1}{2} = \frac{3}{8}$ of an inch, and draw the line BC. The width of the threads and grooves, and also the depth of the threads, is one-fourth of the pitch, or $\frac{3}{4} \times \frac{1}{4} = \frac{3}{16}$ inch.

Through the points K, L, M, etc. draw faint pencil lines KX, etc. to represent the back edges of the threads, and make the parts that are seen full lines. Through the point K draw a faint pencil line KR at right angles to the center line mn, intersecting the line FH in a, and draw the line Ta, which represents the bottom of the thread. The remainder of the screw should now be drawn without any trouble.

26. Fig. 3 is a **single V-threaded screw** $1\frac{1}{4}$ inches in diameter and having 7 threads to the inch; that is, the pitch is $\frac{1}{7}$ of an inch. Draw a cylinder $1\frac{1}{4}$ inches in diameter, having mn for the center line. Lay off AB, BC, CD, etc. each equal to the pitch, or $\frac{1}{7}$ inch. Do the same on the left-hand side. By the aid of the T square and 60° triangle make the angles AOB, $FO'G$, etc. The rest of the thread can be drawn by referring to the figure.

27. Fig. 4 represents a screw exactly like the preceding one, except that the thread is left-handed instead of right-handed, as in the previous case.

To ascertain whether a thread is left- or right-handed, hold the screw in such a position that its axis is horizontal. If the thread is right-handed, as it usually is, the angle that the edge of the thread makes with the horizontal on the right-hand side is obtuse; if left-handed, it makes an acute angle with the right-hand side of the horizontal. No further instruction should be necessary for drawing the thread.

28. Fig. 5 represents a **double V-threaded screw** $1\frac{1}{4}$ inches in diameter. It has $3\frac{1}{2}$ threads per inch; that is, the pitch is 1 inch $\div 3\frac{1}{2} = \frac{2}{7}$ inch. The same remarks regarding the drawing of it apply here that were used in describing Figs. 2 and 3.

29. Fig. 6 represents a section of a **brass nipple.** When the diameter of a nipple is given, the inside diameter is always meant, unless otherwise specially stated. The actual diameter of a nipple or pipe is very rarely given, but must be taken from printed tables. The *nominal diameter* of the nipple shown in the figure is 1 inch, but the actual inside diameter is 1.05 inches; from the table, the outside diameter is found to be 1.32 inches, making the thickness .135 of an inch. Owing to the thinness of the shell, pipe threads are finer than the threads on the same-sized rods. The coarsest pipe thread is 8 threads per inch. The number of threads per inch on the nipple shown is $11\frac{1}{2}$. The thread is tapered to make a tight fit, and the length of the threaded part on each end is $0.52 + 0.53 = 1.05$ inches, of which length the distance between a and b represents the perfect thread, while from b to c the thread is chamfered; that is, it dies out gradually. To draw the nipple, make a sectional view as shown. Draw a cylinder 1.32 inches in diameter and having $m\,n$ as a center line; lay off the inside diameter equal to 1.05 inches and draw $A\,B$ and $C\,D$. Now lay off the diameter $H\,K$ equal to 1.26 inches. Then lay off the distances $H\,J$ and $K\,L$ equal to $0.52 + 0.53 = 1.05$ inches:

join the points H and J, and K and L, by straight lines representing the top of the threads. Now, on the center line $m n$, or on any line parallel to it, lay off a distance of 1 inch from the line $A C$ downwards. Divide this distance into $11\frac{1}{2}$ parts by means of the method given in *Geometrical Drawing*. Project the points just found upon $H J$, and, by means of the **T** square and 60° triangle, draw the threads from H to J as though all the threads were perfect. Draw the threads on $K L$ in the same manner, remembering that the divisions on $H J$ are to be advanced half a thread, as shown; that is, the top of one thread and the bottom of the preceding thread on the other side will be on a horizontal line. Now lay off the distance $a b$ equal to 0.52 inch and project it on lines drawn parallel to $K L$ and $H J$ and touching the bottom of the threads. From the points of intersection draw straight lines to J and L, in order to obtain the bottoms of the imperfect threads extending from b to c. Complete the rest of the drawing in the same manner.

30. Fig. 7 shows another method of representing a **V**-threaded screw. This method has the advantage of making a neat-looking drawing and of being very rapid in delineation. The pitch is laid off as in the three preceding figures. The heavily shaded lines represent the bottom of the thread and their lengths are determined by constructing an equilateral triangle on the pitch distance, as shown, and limiting the line to distances between two corresponding vertexes of the triangle. The diameter of the screw is 1 inch and the number of threads per inch is 8.

31. Fig. 8 represents the same screw shown in Fig. 7, but the lines indicating the bottom of the thread are left out altogether. This method is used on drawings where haste is necessary. Unless in very much of a hurry, the method shown in Fig. 7 is to be preferred. Ordinarily, when drawing screws as represented by Figs. 7 and 8, it is not customary to lay off the pitch and the depth of the thread as above mentioned—the distances between the lines

representing the threads are simply gauged by the eye; practice will enable this to be done very quickly and accurately.

32. Fig. 9 shows two views of a small **hand wheel.** To draw it, locate the center O, and through O draw the center lines $t\ v$ and $m\ n$ at right angles to each other. From O as a center, with the compasses set to the radius of the wheel, or $3\frac{1}{4}$ inches, draw the outer circle of the rim; then, lay off the thickness of the rim, which is $\frac{5}{8}$ of an inch, and draw the inner circle. Through O, with the T square and 60° triangle, draw the center lines $A\ B$ and $C\ D$. With O as a center, draw two circles, one having a diameter of $\frac{5}{8}$ inch, to represent the hole, and the other a diameter of $1\frac{1}{4}$ inches, to represent the outside of the hub. To draw the arms, make the chords of the arcs $a\ b$, $c\ d$, etc. each $\frac{1}{2}$ inch long. Make the chords $h\ l$, $i\ k$, etc. each $\frac{3}{8}$ inch long and draw $l\ b$, $h\ a$, $k\ d$, etc. With a radius equal to $\frac{1}{4}$ of an inch, describe the fillets, or arcs, $A'\ B'$, $C'\ D'$, etc. tangent to the arms at A', B', C', etc. With a radius equal to $\frac{1}{8}$ of an inch, describe the fillets or arcs tangent to the inside of the rim and to the arms. All these arcs terminate at the point of tangency. The cross-section part on the arm indicates that a cross-section taken at $E\ F$ would look as shown; that is, that the arm is elliptical.

The other view shows a conventional method largely used in drawing rooms of indicating a section of the wheel. It is termed a conventional method because it would really be impossible to obtain a section like the one shown. Theoretically, the arm in this view should be sectioned, but, for convenience, a section is imagined to be taken through the rim and hub on the line $t\ v$ and turned around to the position $m\ n$, and the two arms are shown in projection as if they were directly back of the line $m\ n$. Draw the center line $p\ q$ and the sections of the rim as shown. Draw the arms from the dimensions given. Draw the hub as shown, using a radius of $\frac{5}{32}$ of an inch to draw the fillets or arcs tangent to $A\ B$ and to the arm; make $O'\ H'$ equal to $O\ H$ in the other view and describe an arc through H' tangent

FLANGE CO

Scale Full

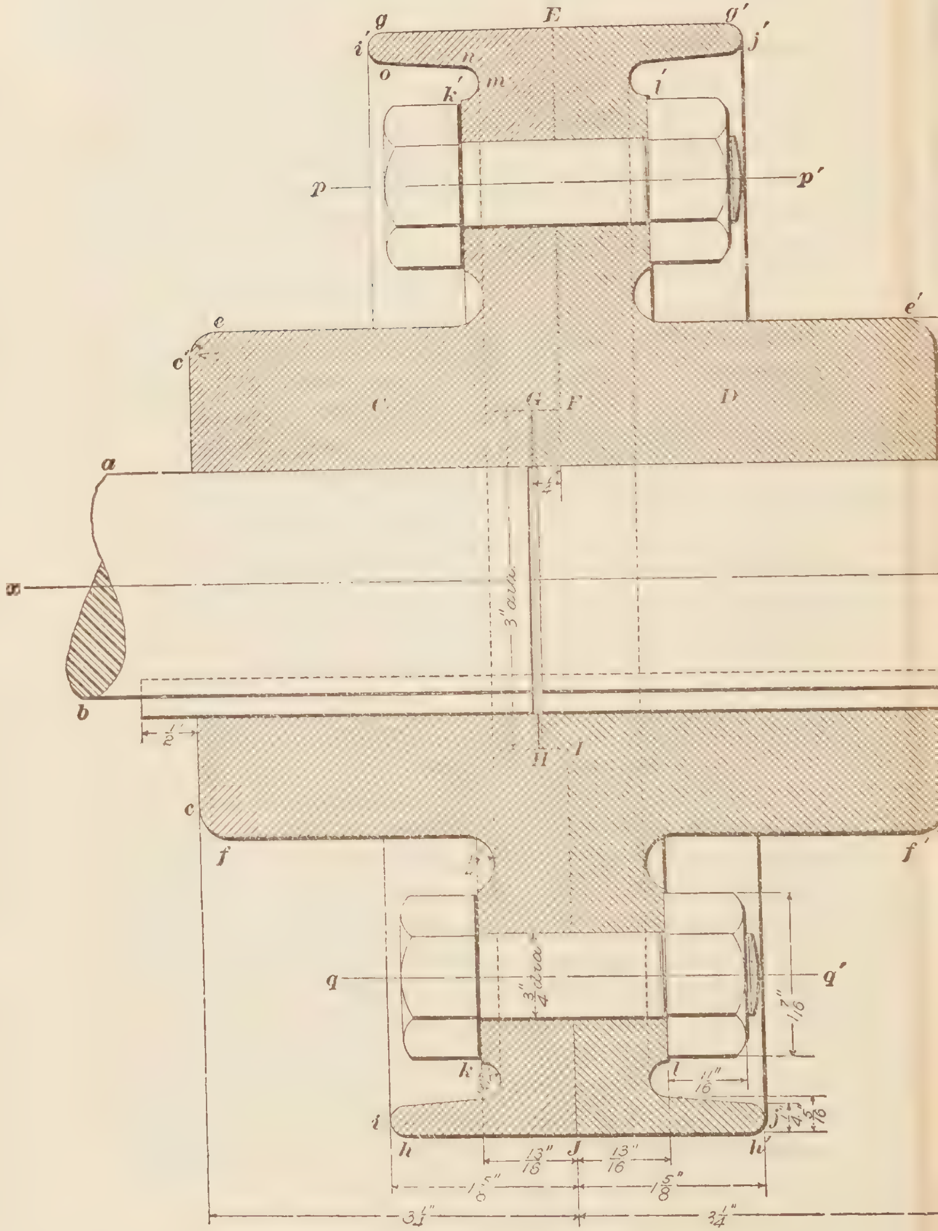


Fig. 1.

LING.

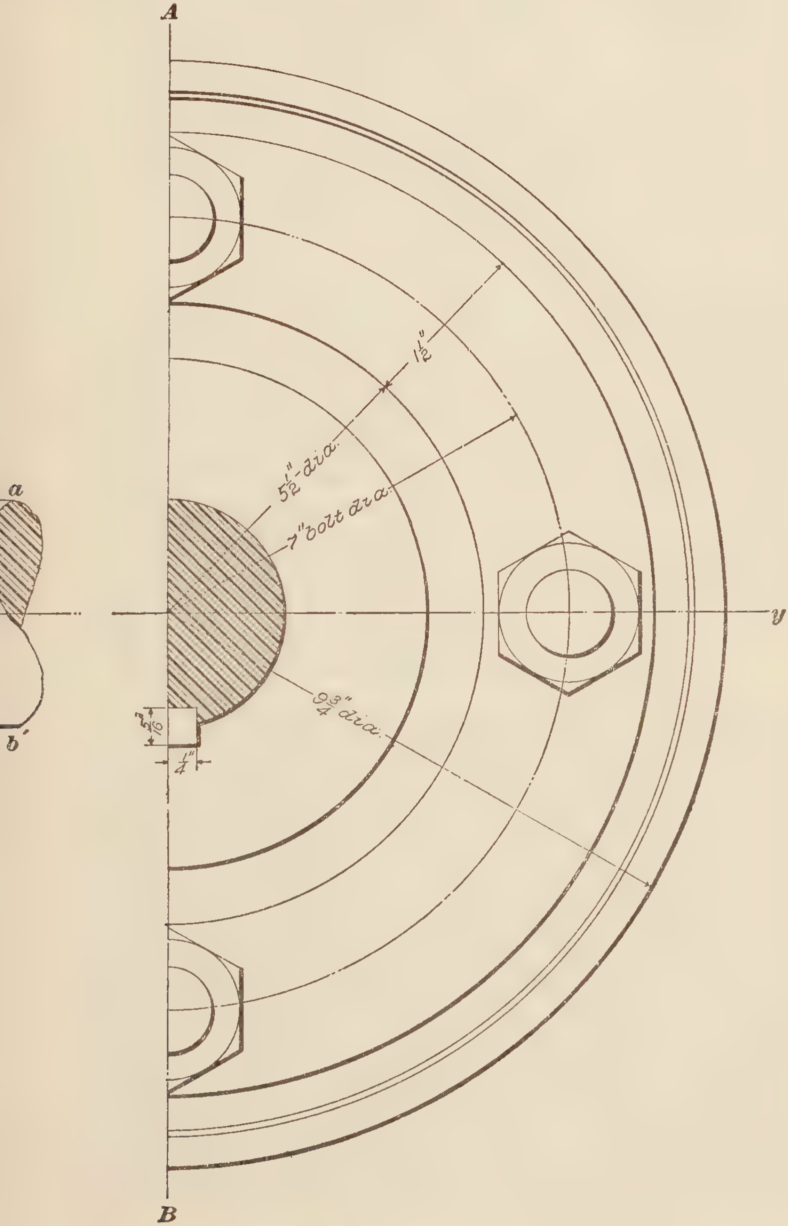


Fig. 2.

owing the title page.

JOHN SMITH, CLASS Nº 4529.

to the two arcs just drawn, which are tangent to AB and the arm. The rest of the drawing can then be completed without further explanation.

33. Fig. 10 shows a **crank,** which should be drawn without difficulty from the dimensions given. The pin is forced in and the end riveted over at AB, to prevent it from being pulled out.

DRAWING PLATE, TITLE: FLANGE COUPLING

34. This plate shows a drawing of a flange coupling suitable for connecting two lengths of 2-inch line shafting. Fig. 1 is a section on the line AB (Fig. 2) and shows how the two parts C and D of the coupling are bolted together through their flanges, hence the name **flange coupling.** Each part is keyed on its shaft separately and true alinement of the shafts is insured by means of the recess in C, into which is fitted a raised boss on D. The two parts of the coupling are first bored and then faced up on the surfaces $EFGHIJ$. They are then clamped together and the keyway is cut. Fig. 2 is a half-end view and needs no comment.

35. To begin the drawing, draw the horizontal center line xy $6\frac{1}{4}$ inches from the lower border line. Draw Fig. 1 first, commencing with the vertical joint line EJ $5\frac{3}{8}$ inches from the left-hand border line. It is now well to draw the shaft. This is 2 inches in diameter; therefore, lay off vertically on each side of xy, $2 \div 2 = 1$ inch, and through the points thus located draw the horizontal lines aa' and bb'. Next draw the hub of the coupling. Lay off $3\frac{1}{4}$ inches horizontally on each side of the vertical joint line EJ and draw cc' and dd'. The diameter of the hub is $4\frac{1}{2}$ inches; therefore, lay off $4\frac{1}{2} \div 2 = 2\frac{1}{4}$ inches on each side of xy and draw ee' and ff'; then draw in the round corners $c'e$, $e'd'$, df', and cf with a radius of $\frac{1}{4}$ inch. To the left of the joint line EJ lay off a distance of $\frac{1}{4}$ inch and draw HG; lay off $3 \div 2 = 1\frac{1}{2}$ inches on each side of xy and draw GF and HI.

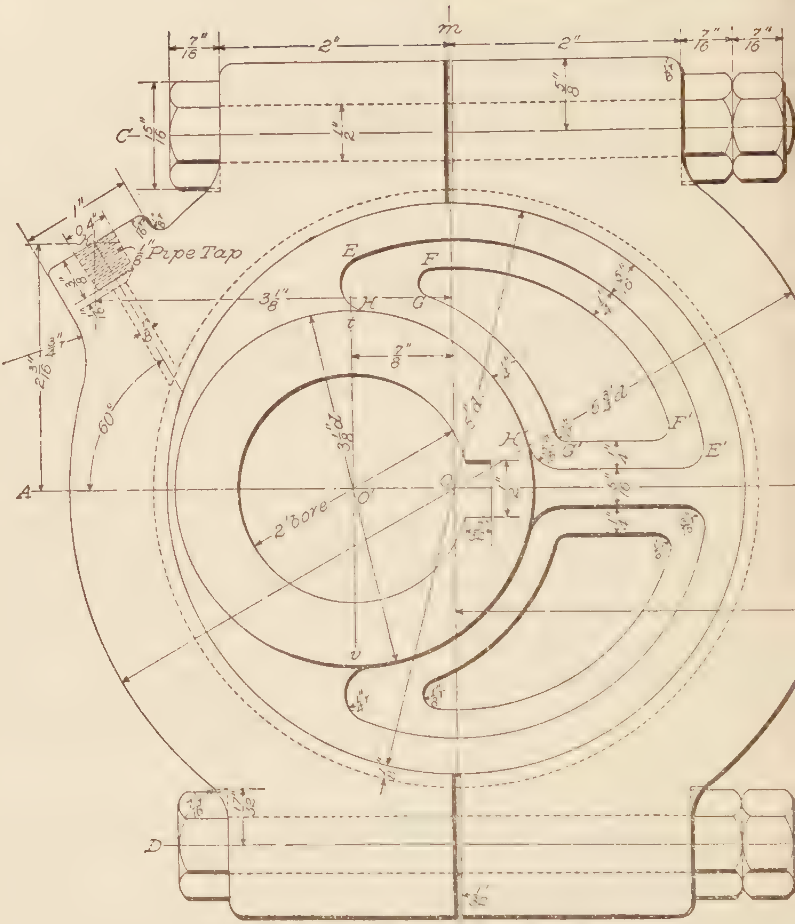
On referring to Fig. 2, it will be found that the outside diameter of the coupling is $9\frac{3}{4}$ inches; lay off half this diameter, or $4\frac{7}{8}$ inches, on each side of the horizontal center line xy and draw gg' and hh'. Each flange is $1\frac{5}{8}$ inches in width on the outer face; lay off $1\frac{5}{8}$ inches to both right and left of EJ and draw the vertical lines ii' and jj', putting in the rounded corners i, i', etc. with the compasses set to $\frac{1}{8}$ inch, in each case completing the circle faintly. Now, draw faint vertical lines kk' and ll' each $\frac{13}{16}$ inch from the vertical joint line EJ. Make kk' and ll' each equal to $8\frac{1}{2}$ inches; to do this lay off $4\frac{1}{4}$ inches vertically on each side of xy and draw faint construction lines $k'l'$, kl. Then with the compasses set to a radius of $\frac{5}{32}$ inch and a center on the line kk' produced, draw the semicircle $k'mn$. Draw no just touching this semicircle and tangent to the dotted circle mentioned above; then draw the other three similar parts of the flange in the same manner. Now, by reference to Fig. 2, locate the bolt center lines pp' and qq'; draw the bolts and nuts and complete Fig. 1 from the dimensions given.

The reference letters printed in bold-face italics should be omitted on the drawing made by the student.

DRAWING PLATE, TITLE: ECCENTRIC AND BRAKE LEVER

36. Fig. 1 shows an elevation of an **eccentric and its strap.** The strap is made in two pieces and bolted together with a small space $\frac{1}{32}$ inch wide between them Locate the point O, the center of the strap, and draw the center lines AB, mn, CC', and DD'. Make the offset OO' one-half of the throw of the eccentric, or, in this case, $\frac{7}{8}$ inch, thus locating O', the center of the eccentric shaft. Construct the rest of the view from the dimensions given, noting that the arcs EE' and FF' are concentric with O, while GG' and HH' are concentric with O'. The part $FF'G'G$ is entirely open and is made so in order to lighten the eccentric.

ECCENTRIC



ECCENTRIC AND STRAP.
Cast Iron. Full Size.
Fig. 1

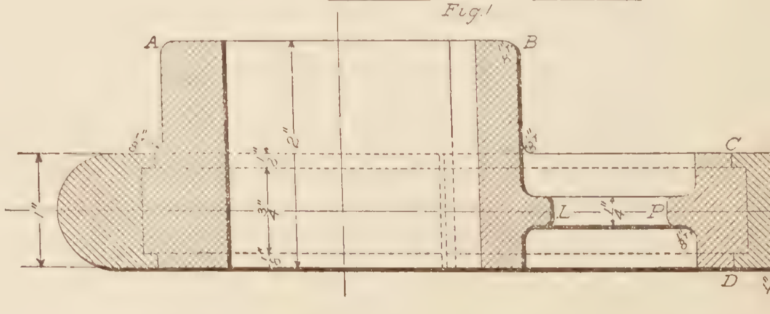
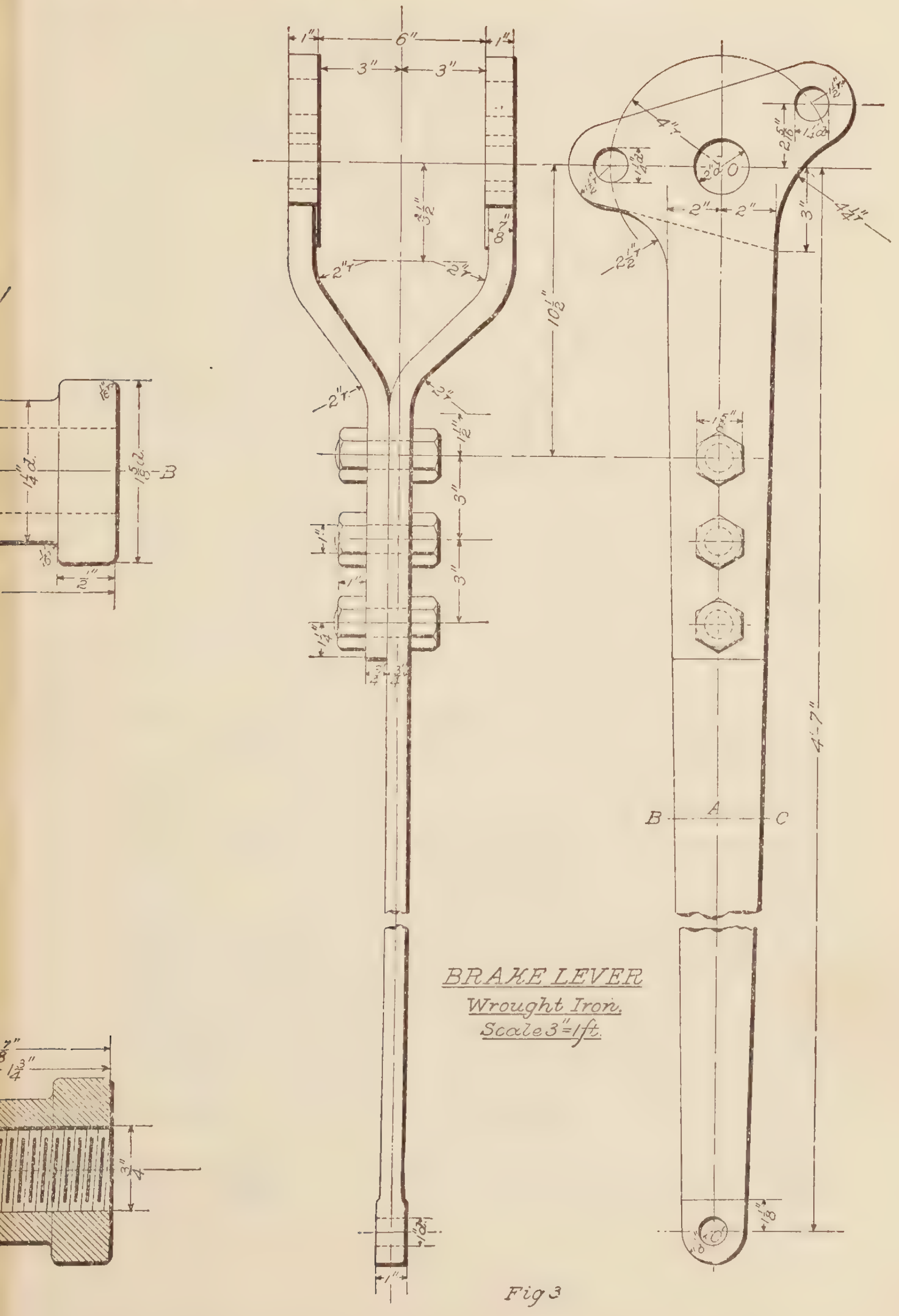


Fig 2.

D BRAKE LEVER.



BRAKE LEVER
Wrought Iron.
Scale 3"=1ft.

Fig 3

37. Fig. 2 is a section of the **eccentric and strap.** The section is drawn in a conventional manner, it being all taken on the line $A\ B$, Fig. 1, except that part of the eccentric between G' and F', where, instead of sectioning, the drawing shows it open from L to P, Fig. 2. This attracts attention to the open part of the eccentric and shows it more clearly.

It will be noticed that the slope of the threads in the sectional part is the same as for a left-handed screw. The thread, however, is right-handed, and the reason for showing it in this manner is that it is the bottom of the thread that is being looked at; that is, the section of a right-handed nut is the same as the projection of the top of a left-handed screw. It will also be noticed that the sectional lines on the eccentric run in opposite directions to those on the strap. This is always done when two different pieces meet and serves to indicate that they are separate pieces. Each piece should be sectioned entirely in the same direction, no matter if there is a break, as in the present case, between L and P. This shows that $A\ B\ C\ D\ E$ is one piece. The dotted hole at K, Fig. 1, is an oil hole.

38. Fig. 3 shows a **brake lever** drawn to a scale of 3 inches = 1 foot. Owing to its length being too great to be shown entirely on the drawing to this scale, the handle is shown as if a piece had been broken out, the dimension line, 4 feet 7 inches, giving the distance between the two centers O and O'. The lever should be readily drawn from the dimensions given. To proportion it properly, where the size of the paper does not permit the whole of it to be drawn, proceed as follows: The length between the centers is 4 feet 7 inches = 55 inches. The width through O' is $2\frac{1}{4}$ inches and through O 4 inches. Hence, $4'' - 2\frac{1}{4}'' = 1\frac{3}{4}''$; $1.75''$ = the taper in 55 inches. Measure off $O\ A$ = say, 2 feet. The width at A may be found as follows: $\frac{1.75}{55}$ = taper in 1 inch. $\frac{1.75}{55} \times 24 = .76$ inch, nearly, the taper in 2 feet.

$4'' - .76'' = 3.24'' = B\,C$, or the width at A. Now locate the point O' and from it as a center describe a curve $2\frac{1}{4}$ inches in diameter. Draw lines tangent to this curve and parallel to the edges between A and O al eady found.

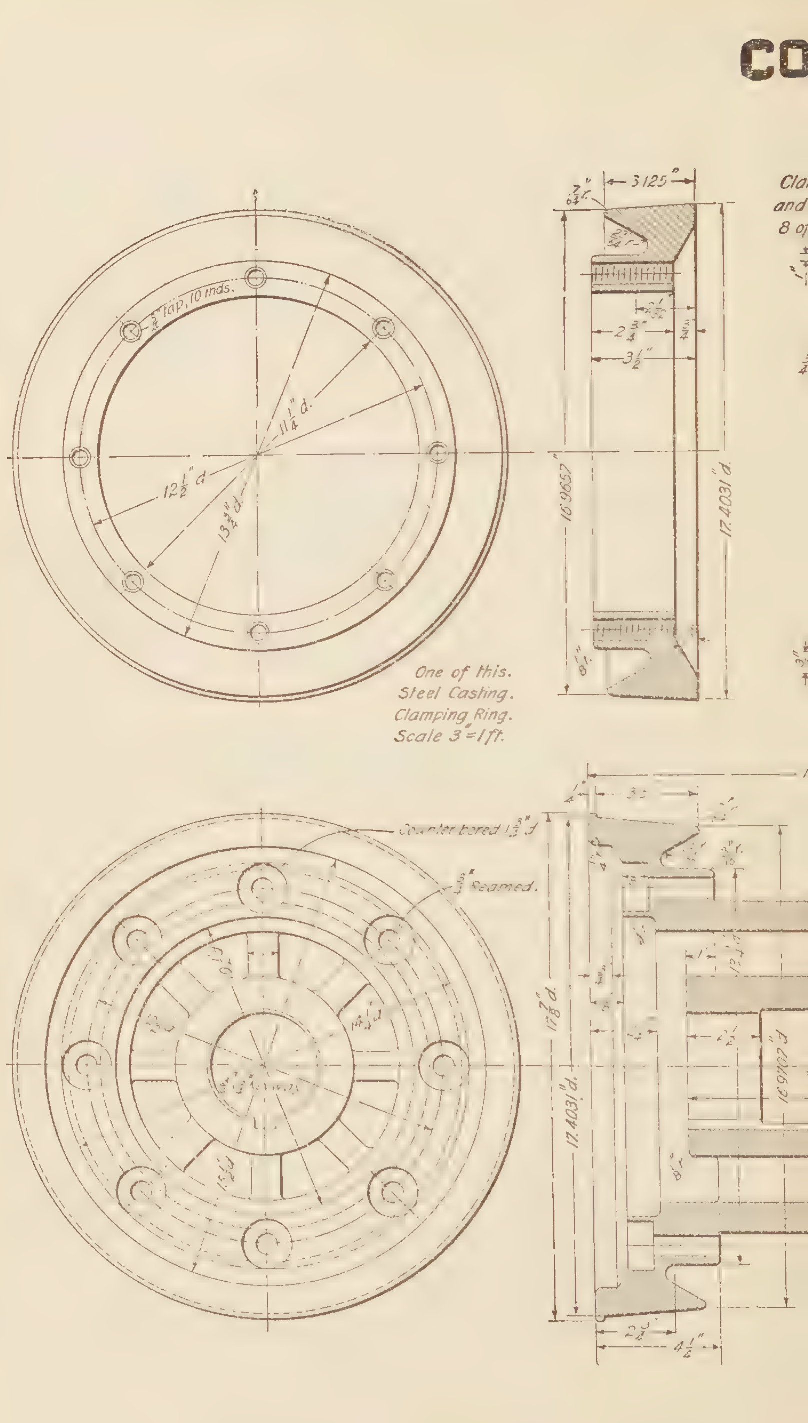
It should be noticed that the center of the brake lever in the left-hand view is not situated at the joint where the two parts come together, but coincides with the center of the handle, as it should do.

DRAWING PLATE, TITLE: COMMUTATOR

39. This plate shows the detail drawings and an assembly drawing of a dynamo commutator. It is composed of a spider and clamping ring, which are drawn together by eight $\frac{3}{4}$-inch bolts and clamp 190 commutator bars separated by mica insulation .04 inch thick. The commutator bars are insulated from the spider and clamping ring by mica rings $\frac{3}{32}$ inch thick.

40. Begin by drawing the clamping ring, locating its horizontal center line $4\frac{1}{8}$ inches below the upper border line and its vertical center line $2\frac{3}{4}$ inches from the left-hand border line. Leave a space of $\frac{11}{16}$ inch between the two views. In the sectional view, which is a section taken on the vertical center line, it will be noticed that the two largest diameters are given to ten-thousandths of an inch. In a shop where many commutators are made from the same drawing, the clamping surfaces (those in contact with the insulation) of the clamping ring, spider, and commutator bars are turned to fit gauges prepared by the toolmaker, who lays out the gauges and makes them to suit the dimensions given. While it cannot be expected that he will get such large gauges as are here required correct to $\frac{1}{10000}$ inch, still the giving of the dimensions in such a small subdivision of the inch calls his attention to the fact that great accuracy is required. This practice of giving *accurate* dimensions in decimals and *approximate* dimensions of a machine part in halves, quarters, eighths, sixteenths, etc. of an inch, is now

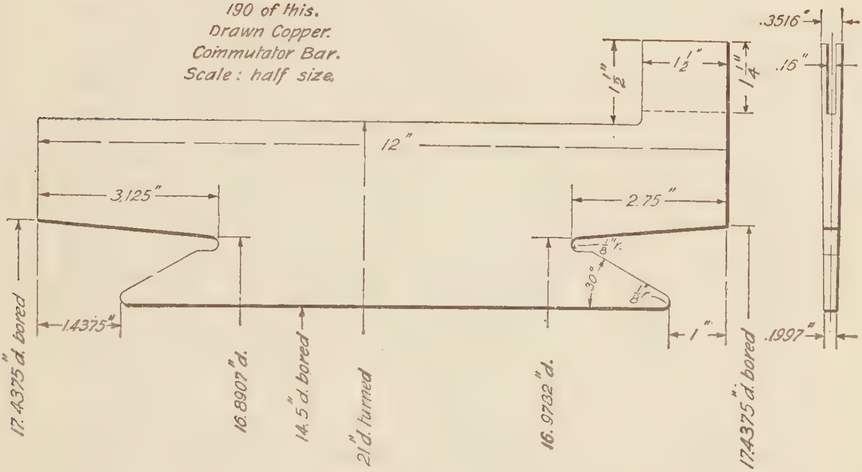
CO



One of this.
Steel Casting.
Clamping Ring.
Scale 3"=1ft.

UTATOR.

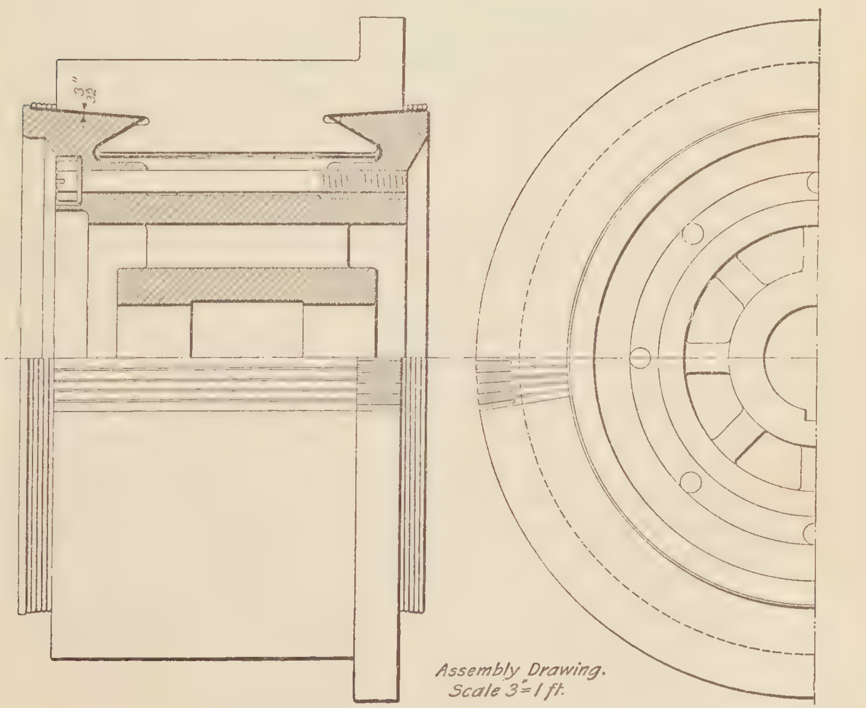
and 6"=1 ft.



190 of this.
Drawn Copper.
Commutator Bar.
Scale: half size.

ng.

ft.



Assembly Drawing.
Scale 3"=1 ft.

immediately following the title page.

JOHN SMITH, CLASS No 4529.

largely adopted in the better class of drafting rooms, the purpose of its adoption being to show the workman at a glance which parts of a machine part require to be very accurate and which do not require it, thus tending to prevent the waste of time incidental to needless accuracy.

41. The spider consists of an outer shell and a hub joined together by eight arms. The hub has a keyway for a $\frac{3}{4}'' \times \frac{3}{4}''$ key, which is let half into the shaft and half into the hub, making the depth of the keyway in the hub $\frac{3}{8}$ inch. Locate the vertical center line in line with the vertical center line of the clamping ring and locate the horizontal center line $3\frac{1}{2}$ inches above the lower border line. Draw this horizontal center line clear across the sheet, as it also serves for the assembly drawing. A space of $\frac{5}{8}$ inch should be left between the end view and the sectional view of the spider.

42. The center line of the clamping washer and clamping bolt should be located $7\frac{3}{4}$ inches from the left-hand border line; the top of the head should be $2\frac{7}{16}$ inches from the upper border line. Owing to the small scale to which the bolt is drawn, it is difficult to draw the correct number of threads per inch (10), and hence the thread is shown exaggerated. This remark also applies to the tapped holes in the clamping ring.

43. Locate the bottom line of the commutator bar $4\frac{13}{16}$ inches below the upper border line and locate the right-hand boundary line $1\frac{11}{16}$ inches from the right-hand border line. Locate the center line of the end view $\frac{3}{4}$ inch from the right-hand border line. The commutator bar is dimensioned with the dimensions required by the toolmaker for making the gauges and by the machinist for turning it to size; consequently, some of the dimensions required for drawing it must be obtained by calculation. Thus, to obtain the depth of the bar at the center, we have 14.5 inches as the inside diameter and 21 inches as the outside diameter of the ring of which the bar is a segment. Then, the depth of the bar is $\frac{21 - 14.5}{2} = 3\frac{1}{4}$ inches. Other dimensions are

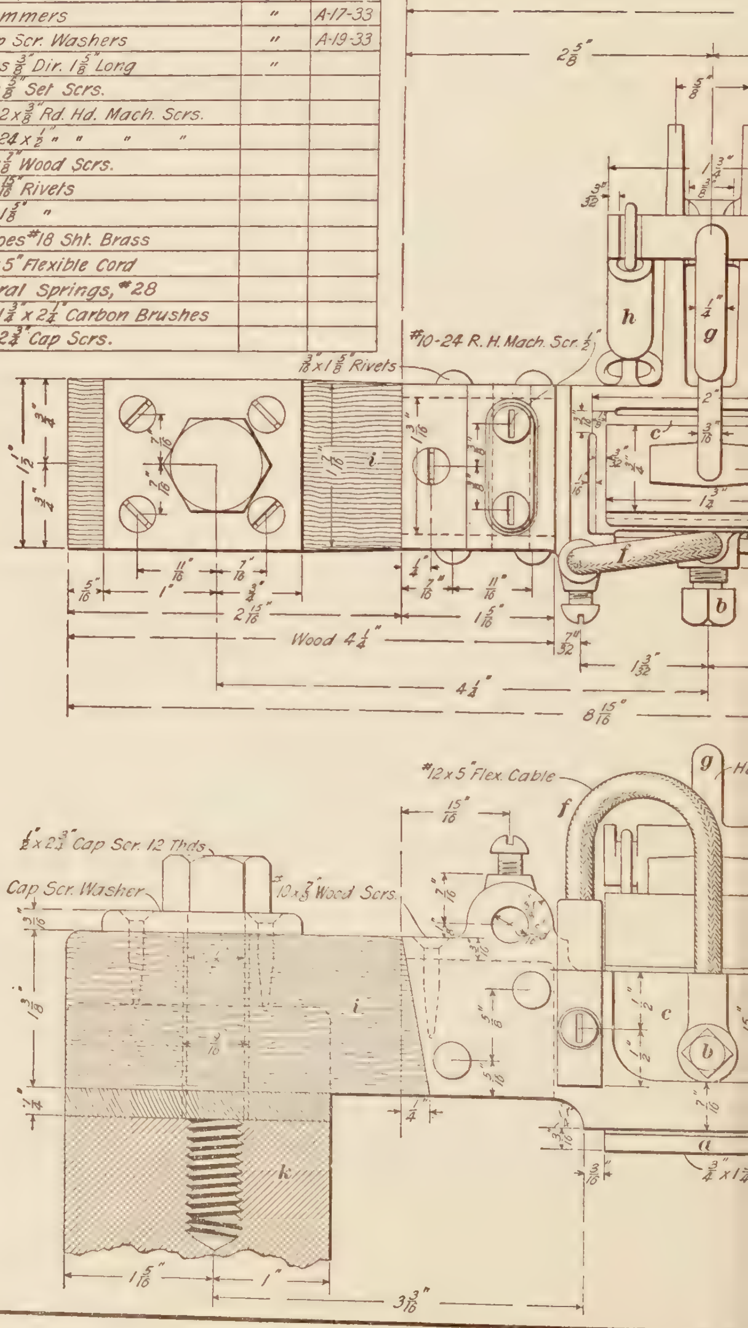
obtained in a similar manner. In regard to laying off the dimensions given in decimals, those appearing on the detail drawings made to a scale of $3'' = 1$ ft. should be laid off to the nearest thirty-second inch (on a scale of $3'' = 1$ ft.), while those on the commutator bar should be laid off to the nearest sixty-fourth inch on a scale of $6'' = 1$ ft.

44. The assembly drawing is made up from the detail drawings, drawing first the spider in the half-sectional view; then the commutator bar, the follower, and the clamping bolt should be drawn. The lower half of the side view can now be drawn. In order to get the assembly drawing within the space available, only half of the end view is shown, it being understood that the omitted part is similar to the part shown. In a working drawing, in order to save time, it is not customary to show all the commutator bars on the assembly drawing, only a few being indicated, as shown. The insulation between the bars being only .04 inch thick, it is not feasible to draw it to a scale of $3'' = 1$ ft. and define its thickness correctly by two lines; consequently the thickness is somewhat exaggerated in the drawing, which under the circumstances is a permissible liberty. Part of the mica insulation between the commutator bars and the spider and clamping ring projects beyond the end surfaces of the bars; it is wrapped securely with a layer of heavy twine well shellacked. In the assembly drawing, the vertical center line of the end view is to be located $\frac{1}{2}$ inch from the right-hand border line and the left-hand surface of the spider $7\frac{7}{16}$ inches from the same border line.

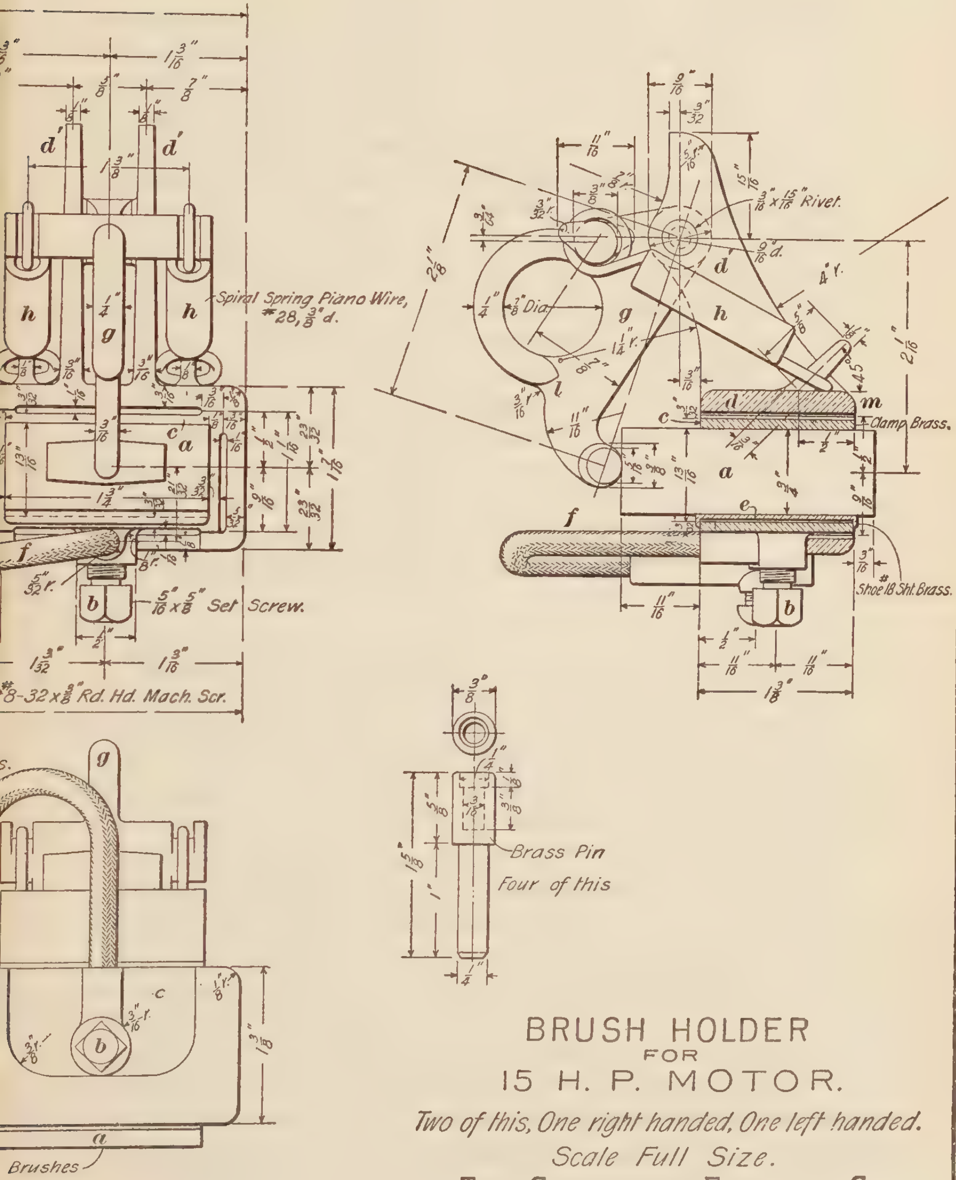
DRAWING PLATE, TITLE: BRUSH HOLDER

45. This drawing plate is a complete working drawing of the left-hand brush holder for a 15-horsepower motor and is designed for the use of carbon brushes, there being four brushes, two in each holder. The carbon brushes *a*, *a* are clamped by means of the setscrews *b*, *b* to the clamps *c*, *c*, which are free to slide in rectangular holes in the body *d* of

120 V.	240 V.	SPECIFICATION D 247	MATERIAL	PATTERN NUMBER
	1	Brush Holder R. Hand	Brass	A-17-30
	1	" " L. "	"	A-17-31
	4	Clamps	"	A-17-32
	4	Hammers	"	A-17-33
	2	Cap Scr. Washers	"	A-19-33
	4	Pins $\frac{3}{8}$" Dir. $1\frac{5}{8}$" Long	"	
	8	$\frac{5}{16}$" x $\frac{5}{8}$" Set Scrs.		
	4	#8-32 x $\frac{3}{8}$" Rd. Hd. Mach. Scrs.		
	4	#10-24 x $\frac{1}{2}$" " " " "		
	10	#10 x $\frac{7}{8}$" Wood Scrs.		
	4	$\frac{3}{16}$" x $\frac{15}{16}$" Rivets		
	4	$\frac{3}{16}$" x $1\frac{5}{8}$" "		
	4	Shoes #18 Sht. Brass		
	4	#12 x 5" Flexible Cord		
	8	Spiral Springs, #28		
	4	$\frac{3}{4}$" x $1\frac{3}{4}$" x $2\frac{1}{4}$" Carbon Brushes		
	2	$\frac{1}{2}$" x $2\frac{3}{4}$" Cap Scrs.		



JUNE 25, 1893.



BRUSH HOLDER
FOR
15 H. P. MOTOR.

Two of this, One right handed, One left handed.

Scale Full Size.

THE SCRANTON ELECTRIC CO.

SCRANTON, PA.,

Drawn by R. B. W. Nov. 6-01.

ediately following the title page.

JOHN SMITH, CLASS No. 4529.

the brush holder. The setscrews *b*, *b* do not bear directly against the brushes, but against a brass shoe *e*. A thorough electric connection between the carbon brushes and the body of the holder is insured by flexible No. 12 cables *f*, *f*, which are composed of strands of copper wire covered with insulating material. The outside diameter of these cables is $\frac{7}{32}$ inch, about. The carbon brushes are held against the commutator by hammers *g*, *g* operated by springs *h*, *h*. The hammers are pivoted to brackets d' cast in one with the body, and the springs are so hung that when the hammers are rotated away from the brushes, the springs will come to the other side of the center around which the hammers turn and thus hold the hammers away from the brushes. The springs are hooked over lugs on the body at one end and over arms projecting from the hammers on their other end. In order to insulate the brush holder from the frame of the machine, it is fastened to a piece of hard wood *i* by two $\frac{3}{16}$-inch rivets and one No. 10 wood screw $\frac{7}{8}$ inch long. The piece of hard wood is fastened to the frame *k* of the machine by a $\frac{1}{2}$-inch capscrew as shown.

46. Begin drawing the plate by drawing the end view, locating the horizontal center line passing through the center of the rivet serving as a fulcrum for the hammer at a distance of $3\frac{7}{16}$ inches below the upper border line and locating the vertical center line $2\frac{1}{2}$ inches from the right-hand border line. The end view is to be drawn first because it is the only view in this particular instance in which everything can be drawn without having to project from another view. For several of the dimensions it is necessary to refer to the top view. The main part of the hammer is flat and has joined to it a handle having a circular cross-section. The flat and round part coming together cause the intersection curve shown at *l*. The distance that the flexible cord *f* projects from the left-hand face of the body is not given on the drawing, as this information would be useless on a working drawing. For the information of the student it is here given, being $1\frac{3}{4}$ inches. It is a general and a good rule with

draftsman not to give any dimensions on a drawing unless they serve a useful purpose; everything superfluous is to be left off. The shoe *e* is marked No. 18 sheet brass; the corresponding thickness is .04 inch, nearly.

It will be observed that the spiral spring *h* is not drawn the way it actually appears, but that it is drawn conventionally. This is merely done in order to save the draftsman's time, as the note "Spiral Spring Piano Wire, No. 28, $\frac{3}{8}''$ *d*," appearing in the top view supplies the necessary information to the mechanic.

47. The end view having been completed, the top view should be drawn next, locating the center of the $\frac{1}{2}$-inch cap-screw fastening the hard-wood strip *i* to the frame $3\frac{1}{16}$ inches from the left-hand border line. This view is drawn partially from the dimensions given and partially by projecting over from the end view. The springs *h* being at an inclination, they appear foreshortened in the top view, and their length in the top view must be determined by projecting over from the end view. Each spring is hooked over a horn cast on the body *d*, a cylindrical ring being formed on the ends of the springs for this purpose. Owing to this ring being at an inclination, it will show elliptical in the top view. The outside diameter of this ring is $\frac{9}{16}$ inch. The heads of the $\frac{3}{16}'' \times 1\frac{5}{8}''$ rivets have a radius of $\frac{5}{32}$ inch and are $\frac{1}{8}$ inch high. The head of the No. 10–24 round-headed machine screws is $\frac{21}{64}$ inch diameter and $\frac{5}{32}$ inch high; the diameter of a No. 10 machine screw is .189 inch, say $\frac{3}{16}$ inch. The head of the No. 8–32 round-headed machine screws is $\frac{5}{16}$ inch diameter and $\frac{9}{64}$ inch high; the diameter is .163 inch, say $\frac{11}{64}$ inch. Machine screws are made in accordance with the standard American screw gauge adopted by all manufacturers of screws; for this reason it is only necessary on a drawing to specify the gauge number of the screw, the number of threads per inch, and the length, which latter is always measured under the head, except in flat-headed screws, where the length is measured over all. Wood screws are measured by the same gauge as machine screws

and bear the same number. The heads of the No. 10 wood screws are $\frac{21}{64}$ inch diameter. The diameter across the flats of the head of the $\frac{1}{2}$-inch capscrew is $\frac{13}{16}$ inch; the height of the head is $\frac{1}{2}$ inch. The $\frac{5}{16}$-inch setscrews have a head $\frac{5}{16}$ inch high and measuring $\frac{7}{16}$ inch across the corners.

48. To draw the side view, begin by locating the edge *m*, which corresponds to the surface *m* in the end view, at a distance of $1\frac{3}{4}$ inches above the lower border line. While all the vertical lines can be projected down from the top view and some of the horizontal lines can be drawn from the dimensions given, the location of other horizontal lines must be determined from the end view. The manner of doing this can best be explained by an example. Suppose we want to locate the centers of the screws *b*, *b* in the side view. Their vertical center lines are easily found by projecting downwards from the top view, but their horizontal center lines must be obtained from the end view. To do this, corresponding edges of the same surface, as, for instance, the surface *m*, in the side view and end view are selected In order to have a line in the end view from which to measure, the line representing the surface *m* should be produced in lead pencil; from the line just drawn a measurement is then taken at right angles to it and to the center line of the screw *b*. This measurement is then laid off vertically upwards from *m* in the side view, and the position of the horizontal center lines of the screws *b*, *b* is thus determined.

In case of doubt as to which side of the selected lines represent the same surface in both views, a certain point in one view is located in the other view being drawn, imagine the two lines to be produced until they meet. Then, evidently, there are two angles formed, one of which, in case the views are at right angles, is 90°, while the other is 270°. Now, everything within the 90° angle in one view is located within the same angle in the other view; likewise, everything within the 270° angle in the one view is located in the same angle in the other view.

The shading of the flexible cords is done freehand.

49. The center line of the brass pin is to be located $4\frac{1}{4}$ inches from the right-hand border line; the center of the top view is to be placed $5\frac{3}{16}$ inches above the lower border line and a distance of $\frac{3}{16}$ inch is to be left between the two views.

50. The first line of the title is a block letter $\frac{3}{16}$ inch high, the second line is $\frac{3}{32}$ inch high, and the third $\frac{3}{16}$ inch high. The fourth and fifth line is written freehand, the capitals being $\frac{3}{16}$ inch and the small letters $\frac{1}{8}$ inch high. The sixth line is composed of capitals $\frac{3}{16}$ inch high, except the first letter of each word, which is $\frac{1}{4}$ inch high. The seventh line is composed of capitals $\frac{1}{8}$ inch high and the eighth line is the same as the fourth and fifth. The student is advised to practice the block lettering shown in this title, but if he desires it, he may substitute the freehand letter shown in the fourth line.

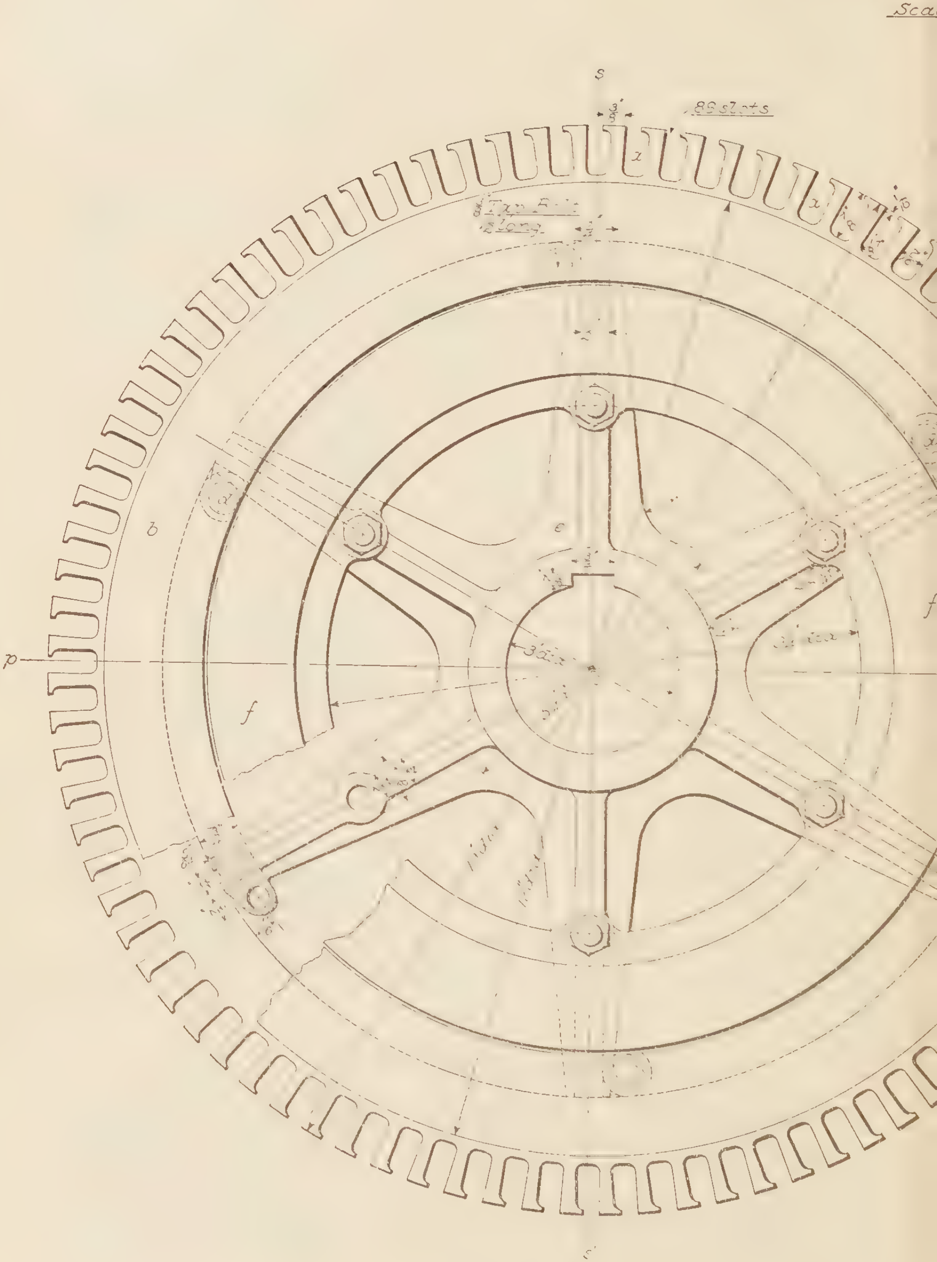
51. In the upper left-hand corner will be found a list of the different parts needed. It is the practice in many shops to have such a list on the drawing for convenience of reference. Draw the bottom line of the list $4\frac{1}{2}$ inches below the upper border line and draw the upper line $3\frac{3}{4}$ inches above the bottom line and divide the space between the two into 17 equal spaces. Draw the left-hand line of the list $\frac{1}{4}$ inch from the left-hand border line and the right-hand line $4\frac{11}{16}$ inches from the border line. To the right of the left-hand border line of the list draw vertical lines at a distance of $\frac{1}{4}$ inch, $\frac{1}{2}$ inch, $3\frac{1}{16}$ inches, and $3\frac{5}{8}$ inches, respectively. Then write in freehand, in the style of lettering shown, all the contents of the list.

The student must omit on his drawing the reference letters printed in bold-face italics.

DRAWING PLATE, TITLE: ARMATURE

52. This plate shows a side view and a section of an **armature** designed for a multipolar direct-connected dynamo. The side view shows the spider *e*, guard rings *f*, and core *g*, with the bolts for holding the different parts together. A portion of the guard ring *f* and of the ring *b*

ARMA



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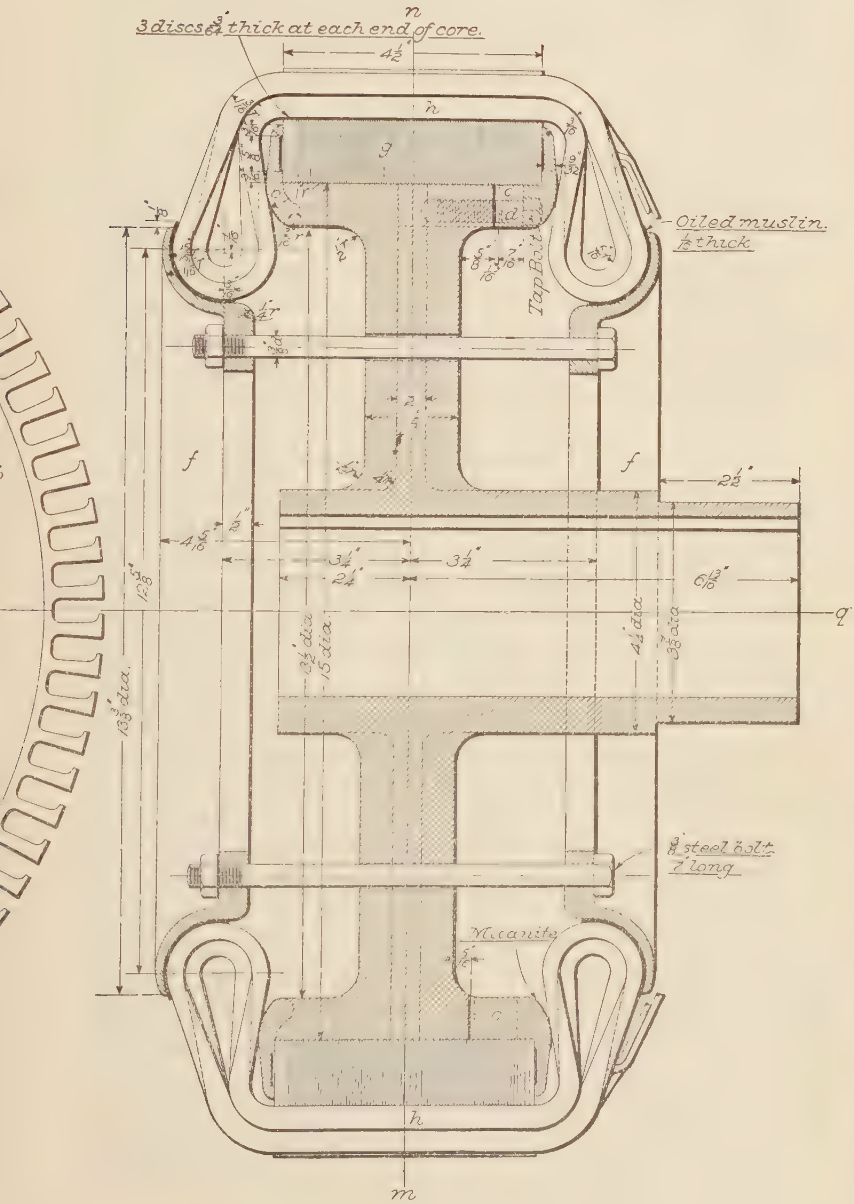


JOHN SMITH, CLASS No. 4529.

joining the arms of the spider are represented as being broken away over one of the arms, so as to show the construction of the arm more clearly. The sectional view, in addition to the parts given in the side view, shows the arrangement of the armature coils *h* in the slots of the core and the insulation that separates the coils from the guard rings, etc. The core is made up of thin rings of sheet iron, having slots *a* cut in them for the reception of the winding; these rings have projections on their inner circumference that fit into grooves in the ends of the spider arms, as shown where the rings are broken away. The projections and grooves prevent the rings from turning around the spider, and the rings are held together on the spider by means of a ring *b* that is cast on the spider arms on one side, and a ring *c* that is fastened to the arms by the tap bolts *d*.

To draw the plate, begin by drawing the horizontal center line pq at a distance of about 6 inches from the lower border line. Draw the vertical center line ss' $5\frac{1}{2}$ inches from the left-hand border line, and the center line nm of the sectional view about 4 inches from the right-hand border line.

Through *o*, the point of intersection of pq and ss', draw the center lines of the arms of the spider at angles of 30° and 90° with the line pq; and with the same point as a center, draw circles representing the hub of the spider, the outlines of the guard ring *f* and of the ring *b*. Draw the outer and inner circumferences of the armature core, according to the dimensions given. Draw a light circle with a radius $\frac{7}{8}$ inch less than the radius of the outer circumference of the core; this will limit the depths of the slots between the teeth of the core.

To draw the arms, first draw a light circle $5\frac{1}{4}$ inches in diameter, and then bisect the angles between the center lines of the arms by light lines. With centers on these bisecting lines and a radius of 1 inch, draw arcs to represent the fillets joining the arms. Lay off the outer ends of the arms on the line representing the inner circumference of the core *g*, according to the dimensions given, and finish them by drawing their outlines as shown.

To draw the slots in the armature core, divide each of the quadrants of the outer circumference included between the vertical and horizontal center lines into 22 equal spaces, then draw light, short, radial lines through each of these points of division. These radial lines will form the center lines of the slots. The student should be able to complete the drawing of the slots and of the remaining details of this view without further instruction.

To draw the sectional view, first lay out the hub, then the arms of the spider, and the rings between which the armature core is fastened, all according to the various dimensions given. Next, draw in the guard rings *f*, *f* and the bolts joining them, after which draw the sections of the armature winding, as shown. Finally, draw the outline of the armature core and the lines representing the division between the rings of which it is made. The remainder of the plate should be completed without further instruction.

The student may omit drawing this plate if he so desires.

TRACINGS

53. In actual practice in the drawing room, it is necessary to have more than one copy of a drawing. It would be very expensive to make a finished drawing every time an extra copy was wanted, and to avoid this, tracings and blueprints are made. Any number of blueprint copies can be made from the same tracing. A complete pencil drawing is made first; then, instead of inking in as heretofore, a piece of tracing paper or tracing cloth of the same size as the pencil drawing is fastened to the board over the original drawing. The tracing paper or cloth being almost transparent, the lines of the drawing can be readily seen through it, and the drawing is inked in on the tracing paper or cloth in the same manner as if inking in a finished drawing.

54. Tracing paper is but little used in America. It is easily torn and cannot be preserved as well as tracing cloth. The two sides of the **tracing cloth** are known as

the glazed side and the dull side; they are also known as the front and the back. The glazed side, or front, is covered with a preparation that gives it a very smooth polished surface; the back, or dull side, has very much the appearance of a piece of ordinary linen cloth. Either side may be used for drawing upon, but when the glazed side is used, care must be taken to remove all dirt and grease, otherwise the ink will not flow well from the pen. This can be done by taking a knife or a file and scraping or filing chalk upon the tracing cloth; then take a soft rag of some kind—cotton flannel or chamois skin—and rub it all over the tracing cloth, being sure to rub chalk over every spot. Finally, dust the rag and remove as much of the chalk from the cloth as can be gotten off by rubbing with the rag. The finer the chalk powder is the better. It is not usual to chalk the dull side, but it improves it to do so. The glazed side takes ink much better than the dull side, the finished drawing looks better and will not soil so easily, and it is also easier to erase a line that has been drawn on this side. Pencil lines can be more satisfactorily drawn on the dull side, and if it is desired to photograph the drawing, it is better to draw on this side. The draftsman uses either side, according to the work he is doing and to suit his individual taste, but if the glazed side is used, *it must be chalked.* The tracings are drawn in a manner similar to the finished drawings, the center lines, section lines, etc. being drawn exactly as previously described.

55. In some offices it is customary to draw the center lines and dimension lines on a tracing in red ink, so that they may appear gray instead of white on the blueprint.

BLUEPRINTING

56. Blueprinting is the process of duplicating a tracing by means of the action of light upon a sensitized paper. The following solution is much used for sensitizing the paper: Dissolve 2 ounces of citrate of iron and ammonia in 8 ounces of water; also $1\frac{1}{4}$ ounces of red prussiate of potash

in 8 ounces of water. Keep the solutions separate and in dark-colored bottles in a dark place, where the light cannot reach them. Better results will be obtained if ½ an ounce of gum arabic is dissolved in each solution.

When ready to prepare the paper, mix equal portions of the two solutions, and be particularly careful not to allow any more light to strike the mixture than is absolutely necessary to see by. For this reason, it is necessary to have a dark room to work in. There must be in this room a tray or sink of some kind that will hold water; it should be larger than the blueprint and about 6 inches deep. There should also be a flat board large enough to cover the tray or sink. If the sink is lined with zinc or galvanized iron, so much the better. There must be an arrangement like a towel rack to hang the prints on while they are drying. For the want of a better name, this arrangement will be called a print rack. The paper used for blueprinting should be a good, smooth, white paper, and may be purchased of any dealer in drawing materials. Cut it into sheets a little larger than the tracing, so as to leave an edge around it when the tracing is placed upon it. Place eight or ten of these sheets upon the flat board before mentioned, taking care to spread flatly one above another, so that the edges do not overlap. Secure the sheets to the board by driving a brad or small wire nail through the two upper corners sufficiently far into the board to hold the weight of the papers when the board is placed in a vertical position. Lay the board on the edges of the sink, so that one edge is against the wall and the board is inclined so as to make an angle of about 60° with the horizontal. Darken the room as much as possible and obtain what light may be necessary from a lamp or gas jet, which should be turned down very low. With a wide camel's-hair brush or a fine sponge, spread the solution just prepared over the top sheet of paper. Be sure to cover every spot and do not get too much on the paper. Distribute it as evenly as possible over the paper, in much the same manner that the finishing coat of varnish would be put on by a painter. Remove the sheet

by pulling on the lower edge, tearing it from the nail that holds it, and place it in a drawer where it can lie flat and be kept from the light. Treat the next sheet and each succeeding sheet in exactly the same manner, until the required number of sheets has been prepared.

Unless a large number of prints is constantly used, it is cheaper to buy the paper already prepared. It can be bought in rolls of 10 yards or more, of any width, or in sheets already cut and ready for use. There is very little, if anything, saved in preparing the paper, and better results are usually obtained from the commercial sensitized paper, since the manufacturers have machines for applying the solution and are able to distribute it very evenly.

57. In Figs. 13 and 14 are shown two views of a printing frame that is well adapted to sheets not over 17″ × 21″.

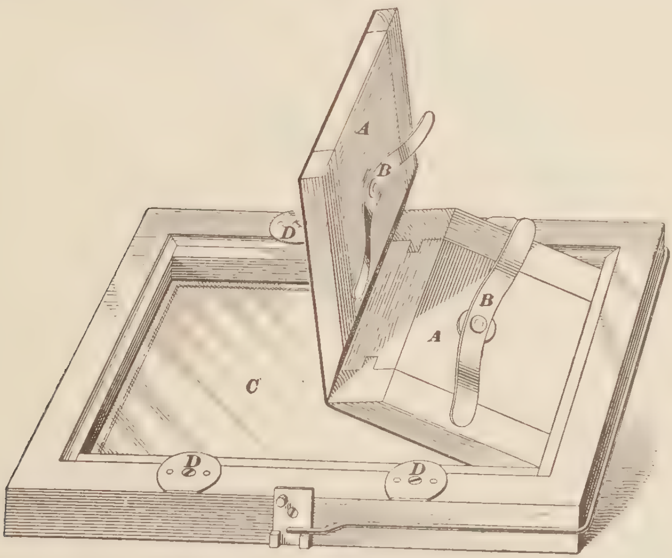


FIG. 13

The frame is placed face downwards and the back *A* is removed by unhooking the brass spring clips *B*, *B* and lifting it out. The tracing is laid upon the glass *C*, with the *inked*

side touching the glass. A sheet of the prepared paper, perfectly dry, is laid upon the tracing with the yellow (sensitized) side downwards. The paper and tracing are smoothed out so as to lie perfectly flat upon the glass, the cover *A* is replaced, and the brass spring clips *B*, *B* are sprung under the plates *D*, so that the back cannot fall out. While all this is being done, the paper should be kept from the light as much as possible. The frame is now placed where the sun can shine upon it and is adjusted, as shown in Fig. 14 so

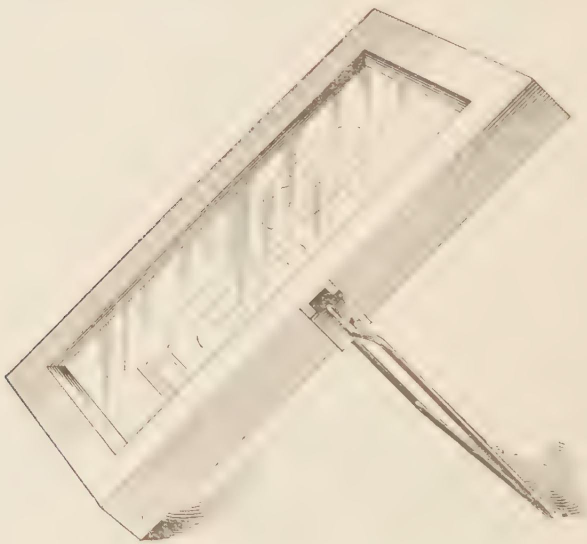


FIG. 14

that the sun's rays will fall upon it as nearly at right angles as possible. According to the conditions of the sky—whether clear or cloudy—and the time of the year, the print must be exposed from 3 to 15 minutes. The tray, or sink, already mentioned, should be filled to a depth of about 2 inches with clear water (rain water if possible). The print having been exposed the proper length of time, the frame is carried into a dark part of the room, the cover removed, and the print (prepared paper) taken out. Now place it on the water

with the yellow side down and be sure that the water touches every part of it. Let it soak while putting the next print in the frame. Be sure that the hands are dry before touching the next print. The first print having soaked a short time (about 10 minutes), take hold of two of its opposite corners and lift it slowly out of the water. Dip it back again and pull out as before. Repeat this a number of times, until the paper appears to get no bluer; then hang it by two of its corners to dry on the print rack previously mentioned. If there are any dark-purple or bronze-colored spots on the prints, it indicates that the prints were not washed thoroughly on those spots. If these spots are well washed before the print is dried, they will disappear.

58. It is best to judge the proper time of exposure to the light by the color of the strip of print projecting beyond the edge of the tracing. To obtain the exact shade of the projecting edge, take a strip of paper about 12 or 14 inches long and 3 or 4 inches wide. Divide it into, say, 12 equal parts by lead-pencil marks, and with the lead pencil number each part 1, 2, 3, etc. Sensitize this side of the paper and, after if has been properly dried, place it in the print frame with the sensitized side and the marks and figures against the glass. Expose the whole strip to the light for one minute; then cover the part of the strip marked 1 with a thin board or anything that will prevent the light from striking the part covered. At the end of the second minute, cover parts 2 and 1; at the end of the third minute, parts 3, 2, and 1, etc. When twelve minutes are up, part 1 will have been exposed one minute; part 2, two minutes, etc., part 12 having been exposed twelve minutes. Remove the frame to a dark part of the room and tear the strip so as to divide it into two strips of the same length and about half the original width. Wash one of the strips as before described, and when it has dried, select a good rich shade of blue, neither too light nor too dark; notice the number of the part chosen, and it will indicate the length of time that the print was exposed. Examine carefully the corresponding

part of the other strip, and the correct color of the edge of the print projecting beyond the tracing is determined. All prints should be exposed until this color is reached, no

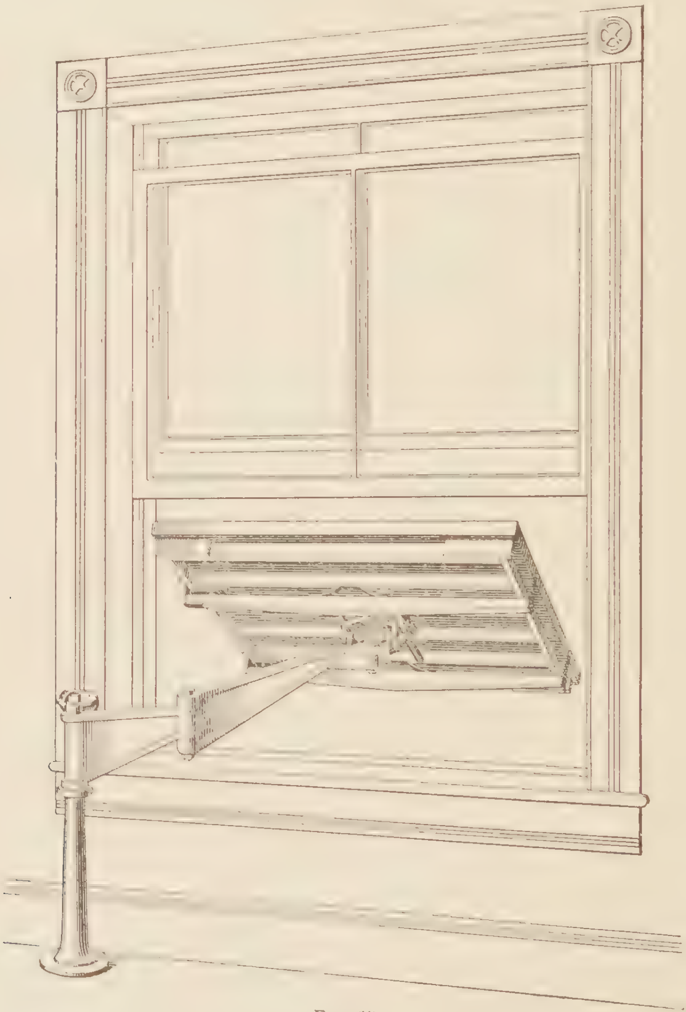
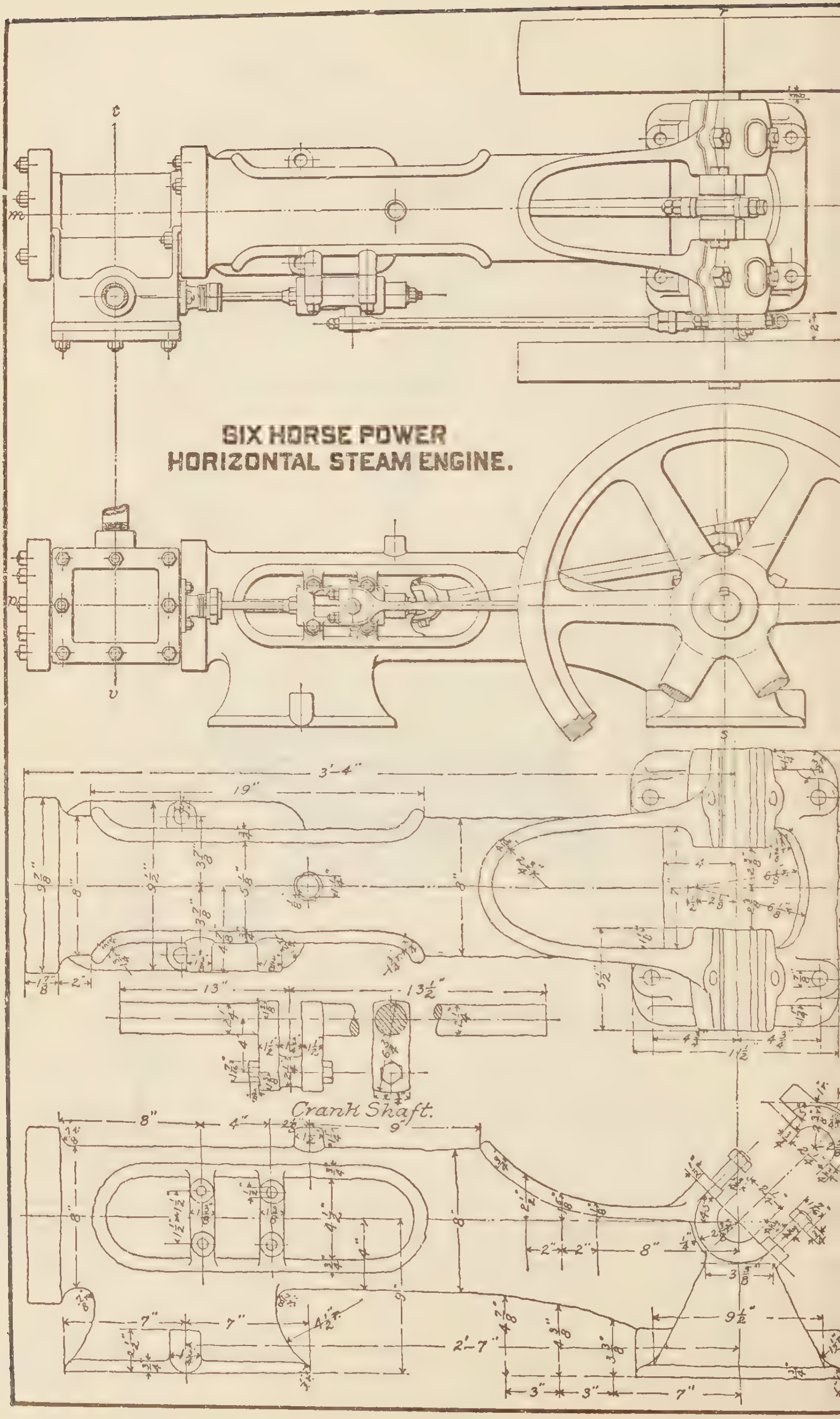
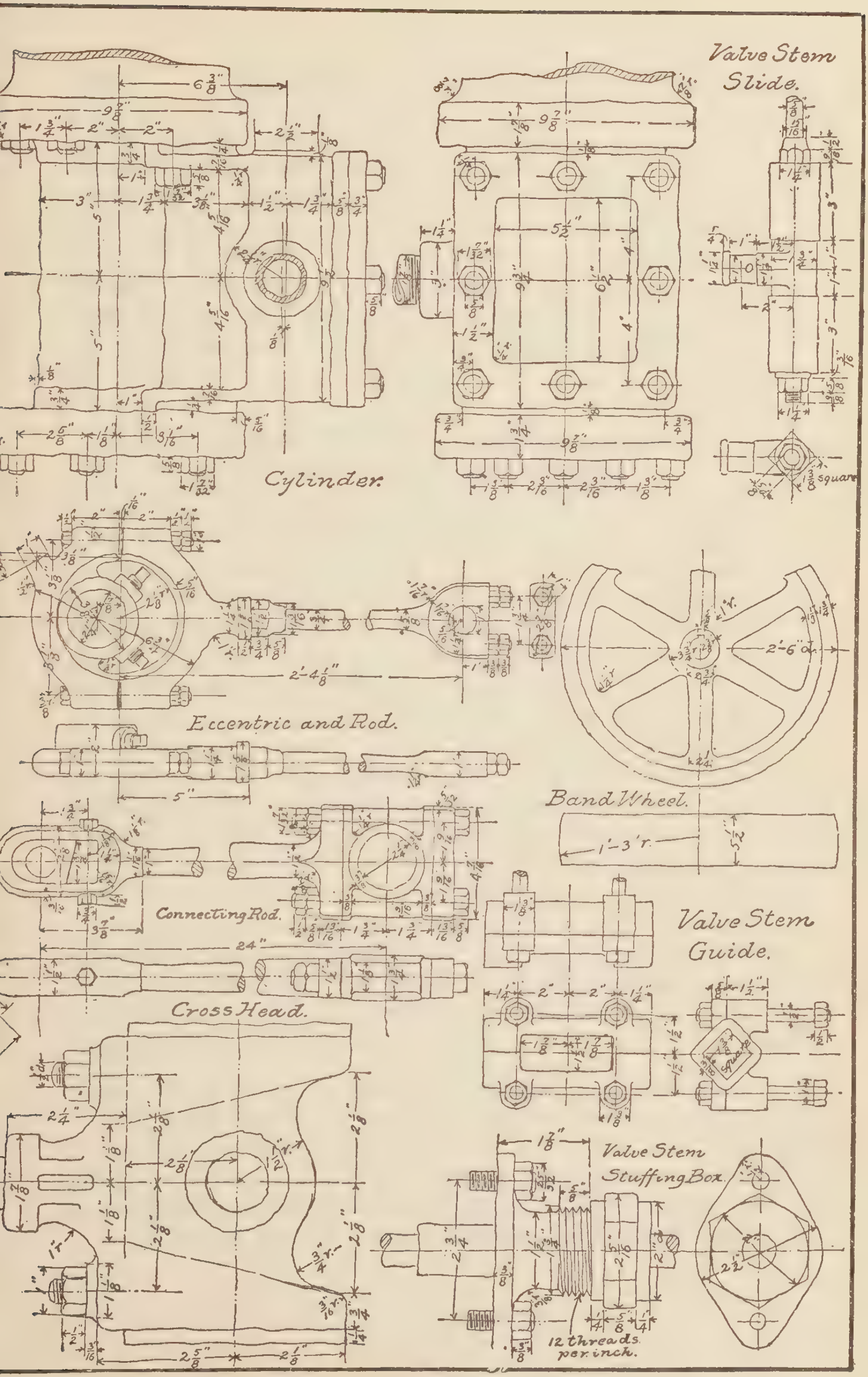


FIG. 15

matter how long or how short the time may be; then they should be immediately taken out and washed.



JUNE 25, 1893.



tely following the title page.

JOHN SMITH, CLASS No 4529.

59. In Fig. 15 is shown a patented frame which can be shoved out of the window and adjusted to any angle. When not in use, it can be folded up against the wall and occupies but little space. It is made in different sizes from 16″ × 24″ to 48″ × 72″. It is one of the best frames in the market, and is placed in such a position relatively to the window that the window can be lowered to the top of the main arm, when it is desired to keep out the cold during the winter.

DRAWING PLATE, TITLE: SIX-HORSEPOWER HORIZONTAL STEAM ENGINE

60. Instead of making a finished drawing of this engine, as in the previous plates, from an exact copy, the student is given the rough sketches of the details of a **six-horsepower horizontal steam engine,** with full dimensions marked upon them; from these he is expected to make a general pencil drawing of the engine in two views—a plan and a side elevation. The details are not to be drawn.

The pencil drawing should then be traced according to the directions previously given. The details are not drawn to scale, but are fully dimensioned. In order to draw the engine to as large and as convenient a scale as possible, it is necessary to make this tracing a trifle larger than the plates that have preceded it. The size over all will be $14\frac{1}{2}'' \times 18\frac{1}{8}''$, with the usual border line $\frac{1}{2}$ inch from each edge all around.

That the student may have a good idea of what he is expected to do, a greatly reduced cut of the general drawing is also given him. All dotted lines indicating parts not seen have been omitted in order to simplify the work. The scale to be used is 3 inches = 1 foot.

61. Draw the center lines $m\,n$, $p\,q$, $r\,s$, and $t\,v$. Draw the side elevation of the bedplate with the bearing caps in position, from the dimensions given on the detail sketches, taking care to make the parts that are likely to be hidden by the flywheel, eccentric rod, etc. light so that they may be easily erased before tracing. The drawing may be traced

without removing the unnecessary construction lines, but it is better to do so, since it lessens the liability of inking in lines that will have to be erased from the tracing.

Draw the plan of the bedplate with the bearing caps, studs, and nuts, foundation-bolt holes, etc. shown in their proper places and positions. The different curves of the bearing caps in the plan should be constructed by projecting points from the view shown in the side elevation. In actual practice in the drawing room, three or four of the principal points (those that mark the limits) would be located and the curves sketched in freehand, they being inked in on the tracing by aid of an irregular curve. In such cases the draftsman has a good idea of the shape of the curves, owing to previous practice in drawing them. When drawing in the curves formed by the opening in the bedplate shown in this view, the student must exercise his own judgment regarding their shape, taking care not to get them too straight. The general drawing gives a good idea of their proper curvature.

Returning to the elevation, draw the crank and crank end of the connecting-rod in the position shown in the general drawing. With the center of the crankpin as a center and a radius equal to the length of the connecting-rod between its centers (obtained from the detail sketch), describe an arc cutting the center line pq at a point that will be the center of the crosshead pin. Draw the crosshead, obtaining the dimensions from the detail sketch. Complete the connecting-rod in both views and draw the piston rod 1 inch in diameter. Draw both views of the cylinder with the nuts and the steam pipe in their proper position, getting all dimensions from the detail sketches.

Draw the center line of the valve stem in the plan view, and draw the stuffingbox, valve stem, valve-stem slide, and its guide in both views. In order to determine the position of the valve-stem slide, it is necessary to locate the center of the eccentric. Referring to the general drawing, it is seen that the eccentric is on the dead center farthest from the cylinder. The offset of the eccentric is given as $\frac{7}{8}$ inch in the detail sketch; hence, when in this position, the center

of the eccentric strap will be situated $\frac{7}{8}$ inch to the right of the crank-shaft center on the line $p\,q$. With this point as a center and a radius equal to the distance between the centers of the eccentric strap and the hole in the stub end of the eccentric rod (see detail sketch), in this case 2 feet $4\frac{1}{8}$ inches, describe an arc cutting the center line $p\,q$ in O; O will be the center of the pin on the valve-stem slide, which may be completed by aid of the detail sketch. Complete the drawing of the eccentric, eccentric strap, and eccentric rod in both views.

Finally, draw in the bandwheel and flywheel (see general drawing for position). The flywheel will be of the same diameter as the bandwheel, but only 3 inches wide.

The pencil drawing is now completed. Before beginning to trace, erase the lines that are not to be inked in. This is not necessary, but it is better to do so, since it avoids confusion and lessens the liability of making mistakes. Some draftsmen prefer to redraw a portion of those parts that are to be inked in with a somewhat softer pencil and leave the light construction lines on the drawing rather than erase them; in some cases, this saves time.

The preliminary directions for tracing a drawing have been given previously. First, trace the side elevation, beginning with the flywheel, and then as much of the connecting-rod, eccentric, and eccentric rod as can be seen. Trace all those parts of the bedplate, cylinder, valve stem, stuffingbox, etc. that are seen. Then trace the plan view, letter the drawing, and draw the border lines. There will be no plate number for this tracing, but the student's name, class number, and the date of completion will be put on as before.

The student should exercise particular care to have every dimension scale exactly the size given in the detail sketches.

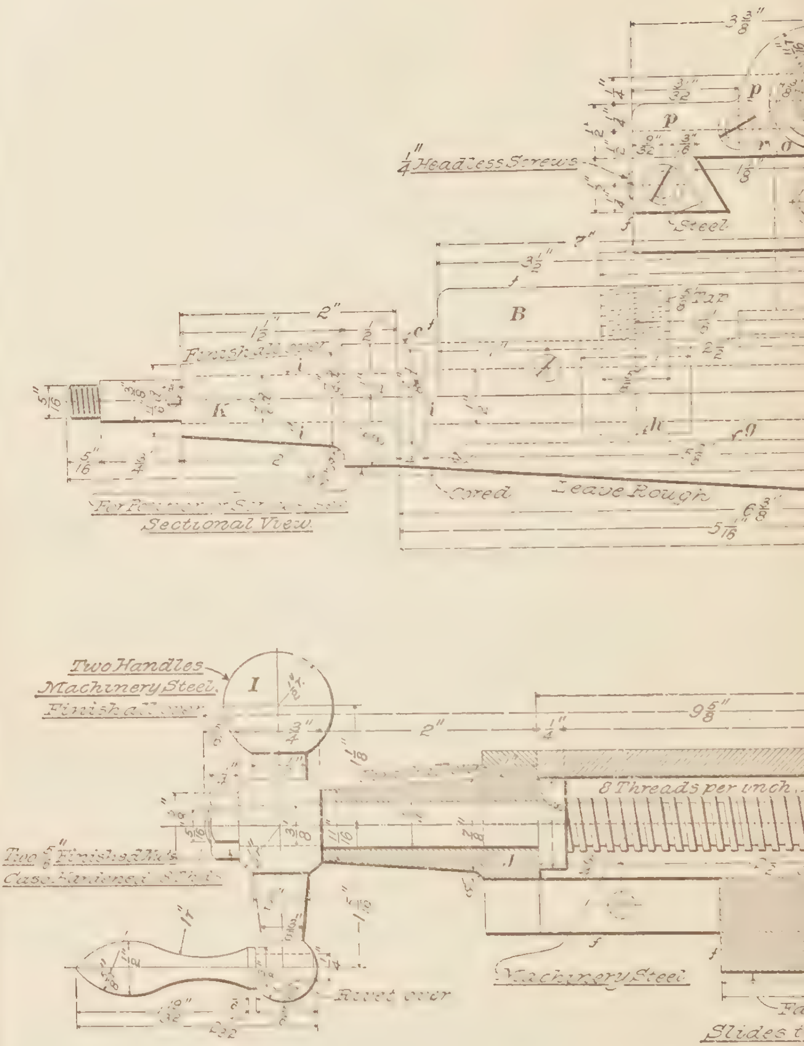
READING A WORKING DRAWING

62. The following general method of procedure has, by experience, been shown to be conducive to the accurate and rapid reading of a drawing made in projection. *First*, if the drawing is dimensioned, ignore the existence of the

dimension lines and dimensions entirely until after the general shape of the object is fixed on the mind. *Second*, by referring to the several views, form an idea of the shape of the main body of the object; that is, observe if its outline shows it to be a cube, a sphere, a cylinder, a cone, a pyramid, etc., or a combination of several of these elementary forms. The shape of the main body having been impressed on the mind, observe how it is modified by details, determining, by reference to the several views, whether they project from the main body or are recesses, or holes. *Finally*, by referring to the dimensions, form an idea of the relative sizes of the component parts. Pay due regard to all conventional representations that may have been used; for instance, do not become confused if the arm of a pulley, or a rib, which, truly speaking, should have been in section, is shown in full. If two half sections are placed on either side of a common center line, remember that each half must usually be viewed independently of the other and must be mentally completed.

63. When reading a drawing in which the views are correctly placed, it is often a great aid to project points or edges of some part the shape of which is doubtful over to another view by the aid of a straightedge, in order to find the location of the doubtful part in another view. When the views are not placed in their correct relative positions, this cannot be done. An example of a case of this kind is given in the plate Compound Rest, and in reading a drawing with the view thus placed, the reader is supposed to constantly imagine that the views are in their correct relative positions; with a little practice this will be found to be quite easy.

64. In a case of this kind, it is manifestly impossible to project points or lines from one view to the other by means of a straightedge, and a different method must be followed. Select some surface whose projection appears in both views, or a center line; now place a pair of dividers so that one point rests on the projection of the surface or center line selected, and open them until the other point reaches the



COMPOUND REST

FOR 10"X 36" SPEED LATHE.

CAST IRON, UNLESS OTHERWISE SPECIFIED,

ONE OF THIS. SCALE FULL SIZE.

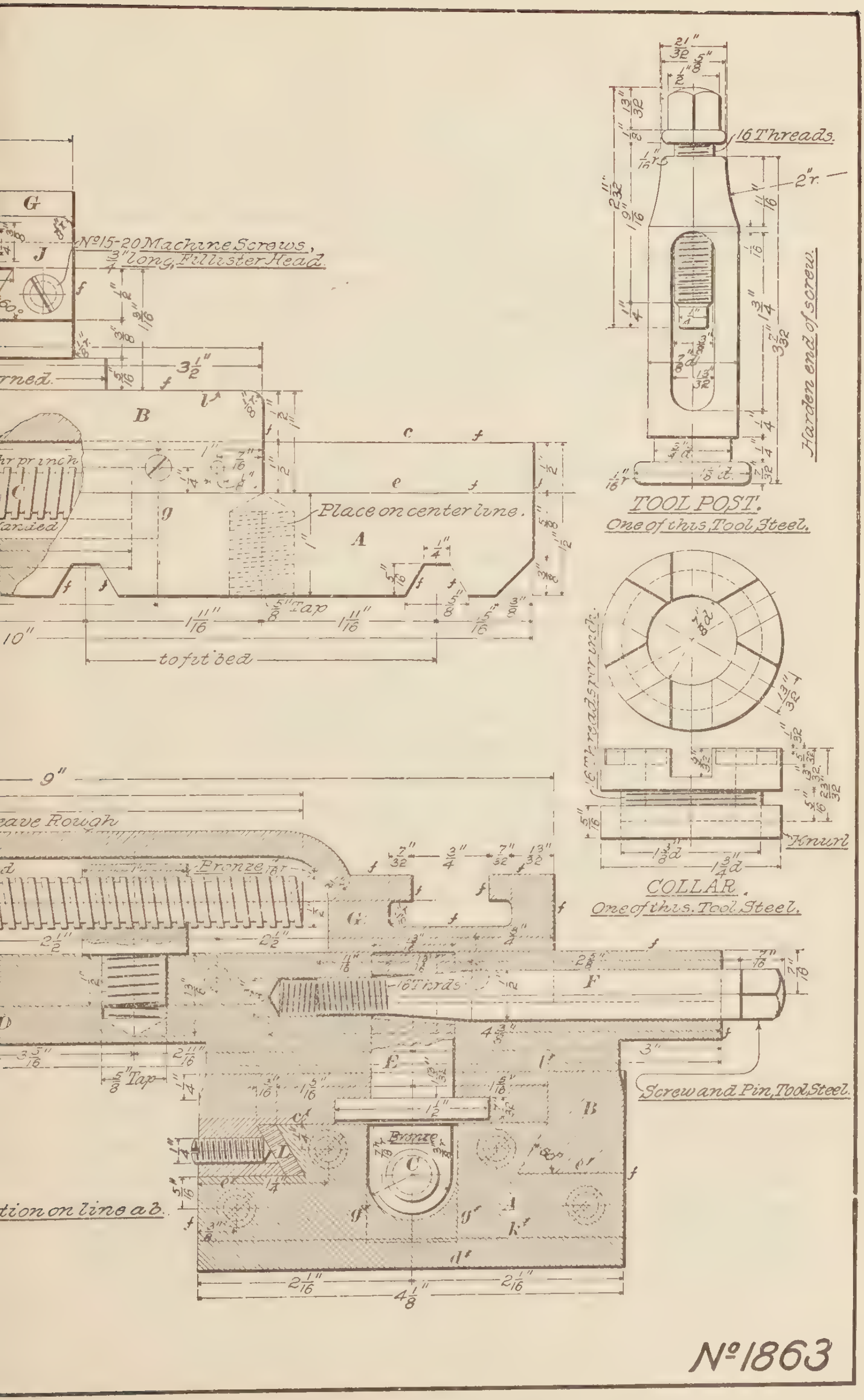
THE SCRANTON TOOL WORKS,

SCRANTON, PA.

Drawn By J.A.G Drawer 182

Checked By C.P.T Order Nº 97

DATE OCT. 1-1900


No15-20 Machine Screws, 3/4" long, Fillister Head.
Place on center line.
to fit bed
Leave Rough
Bronze
16 Thrds
Screw and Pin, Tool Steel.
tion on line ab.
16 Threads.
Harden end of screw.
TOOL POST.
One of this, Tool Steel.
Knurl
COLLAR.
One of this. Tool Steel.
No1863

point or line whose projection it is desired to find in the other view. Then place one point of the dividers on the line representing the selected surface in the second view, and move the dividers along this line until a line, or the projection of a line, is found to coincide with the other point of the dividers. Examples of this will appear later on.

In order to aid the student to read a drawing, a working drawing of a compound rest is shown in Fig. 16; it will be shown in detail by what process of reasoning this drawing is read.

65. To find the shape of the different parts and also to discover, if possible, the relation between them, we must commence our investigation somewhere. Let us choose the bottom of the front view. Looking at this it is noticed that a partial section is shown, from which, by reason of the section lining running in opposite directions, we conclude that A and B are separate parts. At the right and left of the front view, the full lines c, c show that some part of A is higher than the bottom of B, but we do not know whether these lines denote the top surfaces of projecting parts between which B is fitted, or if c is the top surface of a raised strip of some kind that extends clear through the inside of B. In order to settle this question, we note whether the top surface is continued somewhere. Looking at the front view, it is seen that the line c is dotted clear through B, which settles conclusively that the part whose top surface is shown by the line c is a raised strip extending clear through B; this fact immediately implies that B has a groove of some kind running through it longitudinally in order to admit the raised strip.

Referring now to the sectional view, which, as previously stated, is a view taken on the line $a\,b$ of the front view, and everything to the right of this line being removed, we may choose the bottom line d' of the sectional view as a base from which to make measurements. From the fact that the section is taken on the line $a\,b$, we know that the line just chosen is the projection of the intersection d of the plane

represented by $a\,b$ with the bottom of A. Measuring from d' upwards to the highest line c' of A in the sectional view, and placing one point of the dividers on d in the front view, it will be seen that the other point coincides with the dotted line forming a continuation of $c\,c$; this shows that c' is the projection of c. In a similar manner, we determine that e' is the projection of e, and tracing the outlines of A in the sectional view, we notice that the raised strip on A has inclined sides. We also notice that B is cut out to suit the profile of A, except that on one side a steel part L is interposed between the inclined sides of A and B; it is also seen that a screw rests with its point against L.

Referring now to the front view, and knowing from inspection of the sectional view that the upper and lower surfaces of the steel part L are flush with c' and e', or c and e in the front view, to determine the length of this part, notice if any dotted or full lines showing its length are shown anywhere at a right angle to c and e. None being found, the conclusion to be drawn is that either the steel part L is as long as A or has the same length as B. A person without any practical experience might conclude that the length is the same as that of A; but any one having engineering instinct or practical knowledge would immediately notice that, as the steel strip has setscrews which evidently serve to push it against the inclined side of A, it would be unnecessary to make the strip the length of A, and hence would immediately conclude that its length is the same as that of B. This latter conclusion is the one the draftsman desired to convey.

66. Looking at the sectional view of A again, we notice that a groove, open on top, is cut into A. To find its length, we must find lines corresponding to it in the front view. Measuring from d' upwards to the bottom of the groove and transferring the measurement to the front view, we find that the dotted line $g\,g$ represents the bottom and end of the groove, which at the left is also shown to be open at the bottom, since the dotted line g curves around and

continues to the bottom of *A*. This is also indicated by the dotted lines *g'* that form an extension of the sides of the groove in the sectional view; measuring from *c'* downwards to the horizontal dotted line joining the ends of *g'g'*, and then passing along *c* in the front view, the point of the dividers will be found to coincide with the point where the dotted line *g* meets the bottom of *A*. From this the conclusion is drawn that the dotted horizontal line joining *g'g'* in the sectional view is the bottom edge of the opening.

67. Looking at the front view, we notice a left-handed screw *C* that is placed within the slot just investigated. Knowing that, in a view in line with its axis, the outline of a screw will be a circle, and knowing that this circle will be found inside of the slot, the screw is readily found in the sectional view. Now, experience teaches us that when a screw is shown in place in a machine drawing, there must also be somewhere along its axis a threaded hole (or a nut) to receive it. Looking at the sectional view, we see the outline of something (marked "*Bronze*") that surrounds the screw. Now, this part, at first glance, appears to be a continuation of the pin *E* directly above it; there are two reasons, however, why this is not the case. In the first place, the part *E* is sectioned for steel; this immediately shows that *E* and the part under investigation are separate parts. Furthermore, when tracing out the shape and positions of the objects in the front view, they will be seen neither to be in line nor to have any connection with each other. To find the part under investigation in the front view, we may take, in the sectional view, a measurement from the center of the screw downwards to the lowest point of the part we are investigating, and then, referring to the front view, proceed along the center line of the screw *C* until we strike the dotted line *h*. Since the sectional view shows only things to the left of the line *a b*, we know that as the part being investigated shows in the sectional view, we must look for it to the left of *a b* in the front view. At the ends of the horizontal dotted line *h* we notice two vertical

dotted lines that show the length of the part under investigation; since these lines terminate against the line *c*, we know that the part butts against the surface of *B*.

This latter conclusion is further confirmed by examining, in the sectional view, the full outline of the part. Referring again to the front view, we see a screw thread indicated in *B* right above the part we are discussing, and in the absence of any indication to the contrary may justly assume that it is a threaded shank by means of which the part is attached to *B*. By this time we are probably convinced that the part we have been investigating is the nut we are looking for, but are not sure of it. To find out, let us try to investigate the whole of the screw. In the front view, the dotted lines *i*, *i* show that the screw has a bearing and also has a collar butting against part of *A*; beyond the bearing the screw shows in full and apparently has a seat for some kind of an attachment which must cause the screw to turn, since a dowel-pin is shown in the seat. Inspecting the sectional view, we find a screw similar to the one under discussion, with a ball handle and retaining nut on the end of it. As we find a note "*Two Handles Machinery Steel, Finish all over*," and as we cannot find any other place for the second handle, we naturally conclude that such a handle is to be placed on the end of the screw *C*. Now, from the fact that the screw is confined longitudinally by the collar and the ball handle, and that there is no thread on the part of the screw between them, we know that the nut must be to the right of the collar; since the part previously investigated is the only part we can find that directly surrounds the screw, we will now be justified in assuming that it is the nut we are looking for.

68. The fact that *A* and *B* are connected together by a screw provided with a handle for turning it will immediately suggest the idea that it is to be used for moving the part *B* along *A*, whence we conclude that *B* is a slide moving on *A*. Knowing this, the logical conclusion is that the piece *L* is a gib used for taking up the wear of the sliding surfaces.

which view is proved to be correct when it is noticed, by reference to the sectional view, that a tightening of the set-screw will tend to draw the wearing surfaces together.

69. Looking now at the part *K*, at the left of *A*, in the front view, considering the part by itself, we cannot tell whether it is an integral part of *A* or a separate piece fastened to it. But as soon as we consider it in connection with the screw *C*, we see that the latter cannot be placed in position unless the part *K* is removable. From this we conclude that the part *K* is separate from *A*. The next question that suggests itself is: How is it fastened on? The note on the front view and the dotted screw heads in the sectional view show that screws with slotted heads are used.

70. As far as the shape of *K* is concerned, the front view shows that it is a cone joining some presumably flat part. Referring now to the sectional view, we discover by measuring successively from the center line and center of the screw *C* that the dotted horizontal line k' represents the lower surface of *K*, and the absence of any other dotted lines in this part of the sectional view indicates that the profile of the flat part of *K* is the same as that of *A*.

71. On examining the sectional view, it is seen that some part of *D*, which from the section lining we know to be separate from *B*, projects downwards from the main body of *D* and is in contact with the upper surface l' of the part *B*. Referring now to the front view and looking along *l*, we find that the part under discussion is cylindrical; this is inferred from the dimension "*4″ turned.*" The main body of *D*, and also the parts *G*, *H*, and *J*, may now be investigated in a manner similar to that in which the relation of *A*, *B*, *C*, and *K* was traced; it will then be found that *D* is a part similar to *A*. Furthermore, the investigation will show that *G* is a slide; this slide is movable by means of the screw *H*, which turns in the bearing *J*.

72. Referring again to the sectional view, we see that *B* and *D* are connected together by a pin *E*, whose purpose is unknown as yet. Examining this pin, we notice that a hole is cut through its upper end and that a screw *F*, with a tapered shoulder to the right of its screw thread, passes through this hole. On close examination, we see that the hole in *E* is so placed that the tapered part of the screw *F* bears against the upper side of the hole. We further notice that the screw *F* is not used as a fastening device to hold any parts of *D* together; this conclusion is forced upon us by the fact that the sectional view shows *D* to be one piece. Now, we know from experience that a screw is used either as a fastening device or to transmit motion; as it obviously is not used for the purpose first mentioned, we conclude that it probably serves for the latter purpose. To make sure of this, we trace out what will happen if the screw is rotated. We then notice that if the screw is screwed inwards, it will raise the part *E*; but as *E* cannot move upwards by reason of being confined by the collar on it, it shows to us that screwing *F* inwards will force *D* down on *B*. The logical inference is that *E* and *F* form a clamping device intended to clamp *B* and *D* together.

Examining the pin *E* again, we do not find anything that would definitely tell whether it is round or square. Here judgment must be used. An experienced person would know upon the first glance that the clamping arrangement shown is an expensive one to make and one not likely to be adopted when it is only required to fasten two pieces rigidly together, in which case *E* might be either round or square. The next inference would be that it is used in order to allow *D* to be rotated around *E* and to be clamped in any position. This supposition requires the pin *E* to be round and is correct in this case.

73. Referring now to the ball handle *I*, of which only one view is shown, the question of whether it is circular or square is immediately settled by experience teaching us that a handle having the shape shown is not likely to be

anything else but round, and in the absence of any note or indication to the contrary, we would be justified in assuming it to be round.

74. As far as the part *G* is concerned, the sectional view shows it to be cored out in order to pass over the nut in which the screw *H* works. The width and profile of the coring must be obtained from the front view, which it will be remembered is a view at a right angle to the sectional view. The natural assumption to make is that the lines giving the width and profile of the coring will be found directly in the vicinity of the screw *H* in the front view. Measuring from the center line of this screw in the sectional view upwards to the line showing the height of the coring, and then transferring this measurement to the front view, we find the full circle *n*. Now, as the coring is beyond the bearing *J*, we know that its profile would show in dotted lines and conclude that the circle *n* represents some part of the bearing *J*. As this bearing has a conical projection, the inference is that the full circle represents the largest diameter of the cone, which is the case. Now, the absence of a dotted line showing the coring forces us to conclude that the dotted line would be directly behind the full circle *n* and is thus hidden. This conclusion is further strengthened by finding two vertical dotted lines *r*, *r* tangent to the circle *n*, and we finally decide that the groove has straight sides with a semicircular top, as given by the dotted lines *r*, *r* and the upper semicircle of *n*. By measuring again in the manner previously explained, we decide that the dotted line *o* is a front view of the nut in which *H* works.

75. At the right-hand end of the sectional view of *G* we notice a T-shaped opening. Referring to the front view, we can easily discover, by transferring measurements, that the dotted horizontal lines *p*, *p* show the length of the slot, which is seen to extend clear across *G*.

76. Referring now to the drawing of the tool post, it will be observed that only one view is given. While this

does not definitely settle that the post is circular in cross-section, common practice would justify a person in assuming, in the absence of any note or any other indication to the contrary, that such was the case. This view is strengthened by the fact that some dimensions are marked *d*, signifying diameter, which term is rarely applied to any but a round object.

77. The two views of the collar give its shape. Referring to the front view, while there is no definite note to that effect, it would be inferred from the fact that a thread is shown that the lower part is separate, being, in fact, a circular nurled nut threaded to receive the upper part.

78. While, generally speaking, any one can learn to determine the shape of objects from a drawing, there are cases that arise in practice where this is very difficult without further verbal or written instructions. The cases in which this usually happens are where coring has various odd-shaped curved surfaces that curve in different directions, as occurs, for instance, with the steam ports and other passages of steam-engine cylinders and other similar work. Practical experience with a certain line of work, and, frequently, a knowledge of the object of the doubtful part, will often allow the reader to form a correct idea of what the draftsman is trying to convey; when this experience or knowledge is lacking, *consult somebody who is likely to know.*

Furthermore, the shape of an object does not necessarily in itself always reveal its purpose. Ability to determine at sight what an object is to be used for involves either a thorough knowledge of a particular line of work—in which case the purpose of objects coming within its range can usually be determined at sight—or a very wide general knowledge of engineering construction.

STEAM HEATING.

INTRODUCTION.

DEFINITIONS.

1. Although steam fitting is a distinct trade by itself, engineers are sometimes called upon to do such work, and are often required to attend to, and to be responsible for, steam-heating plants.

The following brief explanation of technical terms used in connection with systems of piping for steam distribution to radiators and heating coils will help to make the text matter clear.

2. A **steam main** is the pipe that conveys steam from the boiler or other source of supply and distributes it to the several branches. It is usually run along the cellar ceiling, being hung from the first-floor beams by adjustable iron hangers. It pitches down from its highest point near the boiler to its lowest point at the farther end of the main. The pitch should be at least $\frac{1}{2}$ inch in 10 feet, so that the water of condensation may freely flow to the lower end of the main.

An **overhead main** is a steam main that is run horizontally, or nearly so, at an elevation higher than the radiators that it supplies. This is supplied from the boiler by a vertical **rising main.**

3. **Risers** are the vertical pipes that rise from floor to floor to convey steam from the steam main to the radiators

or coils on the several floors. **Drop risers** are those in which the steam flows downwards to the radiators or coils from a steam main above, usually in the attic.

4. **Riser connections** are the pipes, usually short and nearly horizontal, that connect the steam main to the lower ends of the risers or an overhead main to the upper ends of drop risers.

5. **Radiator connections** are the pipes that connect the radiators to the risers or mains; they are usually short and seldom larger than 2-inch pipe.

6. A **return main** is a nearly horizontal line of pipe, usually run near or under the cellar floor; it receives all water of condensation from the heating system and returns it to the boiler or otherwise disposes of it.

7. **Return risers** are those vertical pipes that take the water of condensation from the radiators or coils on the several floors of a building and convey it to the return main.

8. A **drip pipe, relief,** or **bleeder** is a small pipe used to drain water of condensation away from a low point, "pocket," or "trap" in the steam pipes.

9. A **dry return main** is one that is run above the water-line of the boiler and, consequently, is partly filled with steam.

10. A **wet return main** is one that is run below the water-line and is filled with water at all times. As a rule, this is more reliable than a dry return main except in places where the main is subject to frost.

11. **Coils** are a number of pipes stacked together for the purpose of giving off heat to the air around them.

12. **Direct radiation** is a term applied to all kinds of coils and radiators that are placed inside the rooms to be heated. This is the most common practice in heating

ordinary buildings because of its cheapness, effectiveness, and simplicity.

13. **Indirect radiation** is a term applied to all kinds of coils, radiators, and other forms of heating surfaces that are located outside the rooms to be warmed. Indirect radiators are usually hung from the cellar ceiling, are encased with a galvanized sheet-iron jacket, and are so constructed that fresh air from the outer atmosphere flows between the heating surfaces and enters the room, thus providing ventilation as well as heat. The radiator itself, however, is concealed from view.

14. **Direct-indirect radiation,** sometimes called **semi-direct,** is a term applied to all kinds of radiators and coils that are located in the rooms to be warmed and are provided with means for fresh air to enter through them to the rooms from the outer atmosphere.

METHODS OF HEATING BY STEAM.

CLASSIFICATION.

15. The various systems of heating by steam may be classed in a general way as (1) *high-pressure systems;* (2) *low-pressure systems;* (3) *vacuum*, or *exhaust*, *systems.*

In the first class are all systems of heating that work on a pressure greater than 10 pounds by the gauge; in the second class are those that work between atmospheric pressure and 10 pounds by the gauge; in the third class are all systems that work at a pressure lower than that of the atmosphere.

Any one of these systems may be subdivided as follows: (1) *The one-pipe system;* (2) *the two-pipe system;* (3) *the two-pipe system with separate return risers;* (4) *the overhead-main* or *drop-supply system.*

These, in turn, may be *gravity-return systems* or *forced-return systems*, and they may have *wet return* or *dry return*

mains. In the **gravity-return system**, the water of condensation flows back to the boiler by gravity. This is used in cases where the full boiler pressure is allowed on the heating system. It cannot be used elsewhere.

The **forced-return system** is that in which the water of condensation is forced back to the boiler from the return mains of the heating system by a pump, steam loop, steam-return trap, or other such contrivance. This is used when the boiler pressure is higher than the pressure in the heating system, as, for example, when a pressure-reducing valve is used on the steam-supply pipe to the heating system.

PIPING SYSTEMS FOR STEAM DISTRIBUTION.

INTRODUCTION.

16. The principal systems of piping that are now in vogue for heating purposes are shown in Figs. 1 to 4. These diagrams are intended to illustrate only the general arrangement of the piping, and many details are, therefore, omitted. The radiators *a*, *b*, *c* are supposed to be located on different floors of a building and at various distances from the vertical supply pipes, or risers. It will be seen by careful inspection of the diagrams that the main difference between the several systems consists in the method of returning the water of condensation to the boiler.

ONE-PIPE SYSTEM.

17. The **one-pipe system** is shown in its simplest form in Fig. 1. Steam flows from the boiler *B* through the riser *s* and is conveyed to the radiators through suitable branches, which are nearly horizontal. All the water of condensation flows backwards through the same pipes, moving in a contrary direction to the steam. All the nearly horizontal pipes,

such as h and e, must, therefore, be inclined sufficiently to secure the ready movement of the returning water. This is purely a one-pipe system and can only be used on very small jobs.

TWO-PIPE SYSTEM.

18. The **two-pipe system** is illustrated by Fig. 2. Each radiator has two connections, one of which serves as an inlet for steam and the other as an outlet for water. The steam supply passes through the pipes h and s and the water flows back to the boiler through the return pipes r and f. The branch e that supplies steam to the radiator b, at a considerable distance from the riser, is inclined so that the water

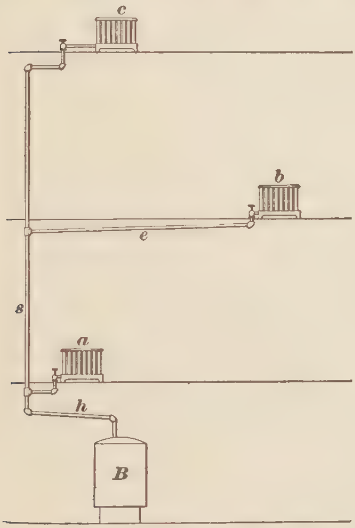


FIG. 1.

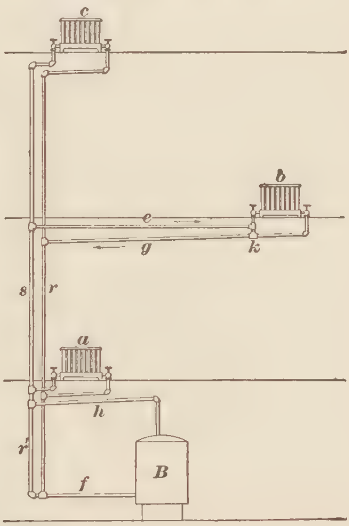


FIG. 2.

formed within it will flow towards the radiator. It is connected at k to the return pipe g by a small relief pipe, so that the water will be drained off and prevented from entering the radiator. The steam main h is also inclined, if it is of any considerable length, so that the water formed within it will run towards the foot of the riser s. All the water

formed in the pipes *h* and *s* is drained off by the *relief pipe r'* Thus the steam and the water are carefully separated at all points in the system.

SEPARATE-RETURN SYSTEM.

19. The **separate-return system** is shown in Fig. 3. The steam-supply pipes are the same in every respect as

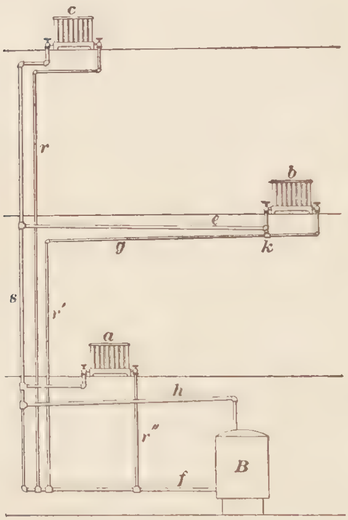


FIG. 3.

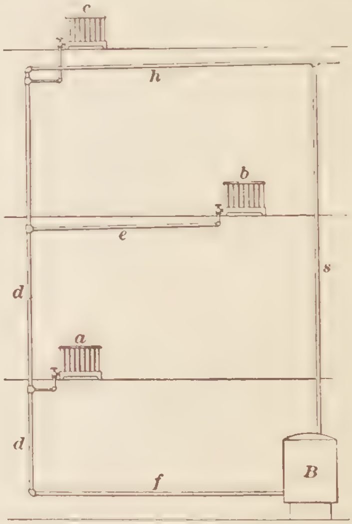


FIG. 4.

in Fig. 2. The returns, however, are different, each radiator being provided with its own separate return pipe, as shown at *r*, *r'*, *r''*.

DROP SYSTEM.

20. The **drop system** is shown in Fig. 4. The steam supply passes up the riser *s* to the top of the system, thence along the horizontal pipe *h*, and descends through the drop pipe *d*. The radiators are connected to the steam supply with single pipes, precisely as in Fig. 1. It will be seen that the water in the pipes *h* and *d* moves in the same direction as the steam, instead of in the opposite direction, as in the

single-pipe system. It is not necessary that the return should be made parallel with the steam-supply pipes, as they are shown in Figs. 2 and 3, but they may follow any convenient route back to the boiler. It is always advisable to make the returns as direct as practicable, care being taken, however, to avoid straggling the pipes about the building in an unsightly fashion.

CIRCULATION.

21. The "circulation," that is, the supply of steam, is far more certain in the two-pipe system than in the one-pipe system, because there is nothing to oppose or interfere with it at any time. Thus, a radiator at the end of a long horizontal branch, as at *b* in Fig. 1, is liable to have its supply interrupted by the formation of the returning water into "slugs," filling the bore of the pipe and causing **water hammer**; but when the pipes are arranged as in Fig. 2, the same formation may happen without causing any trouble whatever.

When steam and water flow in the same pipe, the steam is likely to be wet, because the separation is less complete than when they are kept apart. When the currents flow in contrary directions, the wetness of the steam is aggravated, and there is such an amount of mechanical interference between them that larger pipes are required than would otherwise be necessary, and there is also much greater liability to water hammer and sizzling noises.

COMPARISON OF SYSTEMS.

22. Occasionally a radiator will gradually fill up with water. This occurs in a one-pipe system when the steam valve remains nearly closed for a considerable time, but not shut tight. The steam is then condensed as rapidly as it enters, and the opening is so restricted that little water will escape. The same thing will happen in a two-pipe system if either of the valves is closed and the other remains open.

By opening both valves wide the water will almost noiselessly pass out into the return, but in the one-pipe system, as soon as the valve is opened, a violent struggle will begin between the entering steam and the escaping water. The result will be a succession of rumbling, hammering, and snapping noises, which will continue for several minutes. If the supply pipe is long, as at *c* in Fig. 1, the noise is likely to be prolonged to an annoying extent.

23. In a large heating system, the amount of water to be returned to the boiler is so great that it becomes very difficult to pass it through the steam-supply pipes without interfering seriously with the flow of steam to the radiators. The difficulty reaches a maximum in the coldest weather, the greatest amount of condensation occurring at the same time that the largest supply of steam is required. A single-pipe system must be carefully planned to avoid failure at this critical time, and it is good policy to attach returns at some of the principal points to intercept the water and prevent its flooding the riser connections.

The two-pipe system, however, when carried out completely, has a certainty of operation and freedom from noise, which in many cases makes it much superior to the one-pipe system.

SUBDIVISION OF LARGE HEATING SYSTEMS.

24. It is advisable to divide all heating systems that are of any considerable extent into several independent sections. Long or troublesome horizontal branches may be reduced to a minimum by using independent or special risers and carefully locating them where they will supply the largest number of radiators to the best advantage. One riser may be used to supply almost any number of radiators, provided that none of them are located so far away as to make it difficult to drain the supply branch. Thus the question of the number of risers to be used will be determined mainly by considering the drainage in the horizontal pipes.

In a very tall building, a single riser may be sufficient, provided that the floors are of moderate dimensions; but if the building covers a large area of ground, two or more risers will be required. In all cases, however, it is advisable to have the branches as short as possible.

Each section of a heating system should be made *independent* of the others, so that it can be closed down for repairs without affecting any other part of the system. Large straightway or gate valves should be placed close to the mains in both the supply and return riser connections.

DESIGN OF PIPE SYSTEMS.

PRECAUTIONS.

25. In planning any system of steam pipes, there are two things to be kept always in mind and that must be fully provided for; these are **drainage** and the movement of the pipes by **expansion.** No heating can be done without condensation, and the water thus produced must be disposed of promptly and completely and in a manner that will prevent interference with the steam supply.

Expansion and contraction are inevitable, and the movement is repeated every time the system undergoes any considerable change in temperature. This movement must be provided for, otherwise it will break the joints and make serious trouble.

STEAM-MAIN ARRANGEMENT.

26. The general arrangement of a **steam main** to supply several risers is shown in Fig. 5. The boiler *a* is set on the cellar or basement floor and furnishes steam to the entire system. The steam main *b*, whose duty it is to convey steam to the several risers *c*, *c*, through which it flows to the radiators *d*, *d*, etc. placed within the rooms to be warmed, is connected to the steam space of the boiler and is so suspended from the floor joists by hangers that it will have a

uniform fall from its highest point, which is immediately above the boiler, to its lowest point *f*. A pitch of about $\frac{1}{2}$ inch in 10 feet is usually considered a sufficient fall for the main. When steam is generated in the boiler, it is forced into the steam main, from there into the risers, and thence into the radiators. The air that the pipes contain is forced out of the system to the atmosphere through air vents or small valves placed at suitable points in the system, usually

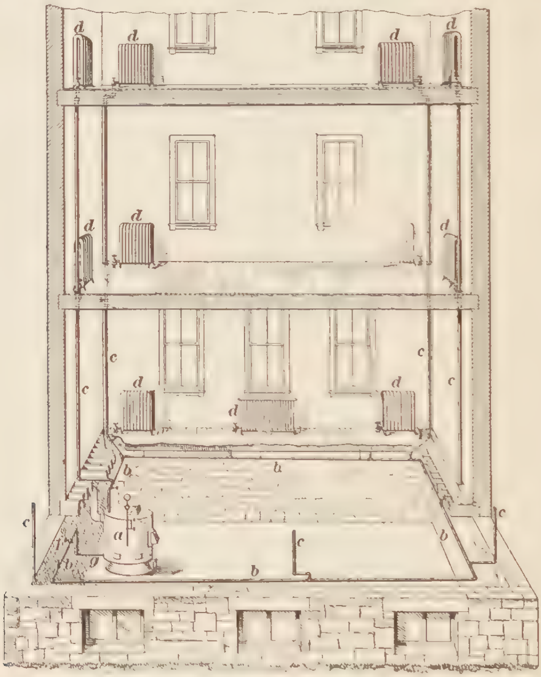


Fig. 5.

upon each radiator at the end opposite the steam inlet. As steam flows through the main and the risers, part of it will be condensed by heat being transmitted through the pipes to the air and objects surrounding them. This condensed steam will fall by gravity to the bottom of the steam main, flow to its lower end *f*, and enter the bottom of the boiler through the return pipe *g*. The water of condensation

from the radiators first accumulates in the base of the radiators until a sufficient hydrostatic head is formed to cause it to flow out of the radiators against the inflow of the steam. It then falls down the risers, through the riser connections, and into the steam main, also against the flow of the steam. If the riser connections to the steam main or radiator connections to the riser have too little pitch, or if the pipes are too small, the flow of the water of condensation through them will be resisted by the flow of steam to such an extent that the water will not flow off as quickly as it is formed, the result of which will simply be that the water will accumulate in the pipe until it entirely closes it, when water hammer will take place. The steam main should be made sufficiently large to prevent such a difference between the pressure in the boiler and that at the point *f* as would cause the water to back up in the main and retard the flow of steam to any riser connection.

DETAILS OF PIPING.

27. Connection of Boiler Main.—In many cases it is advisable to connect the steam pipe leading from the boiler to the mains at a point near the middle of their length, as at *a* in Fig 6. The pipes may then be graded downwards from *a* in both directions.

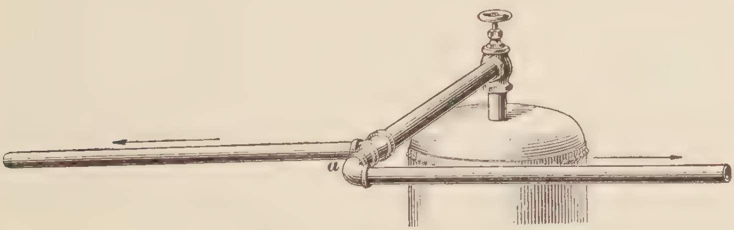


FIG. 6.

28. Relays.—When a main or any horizontal steam-supply pipe has to be run a long distance, it becomes impracticable to grade it uniformly throughout its whole length,

because the far end drops too low to be drained conveniently. In such a case, the difficulty may be overcome by introducing *vertical offsets*, or **relays**, in the line of pipe, as shown in

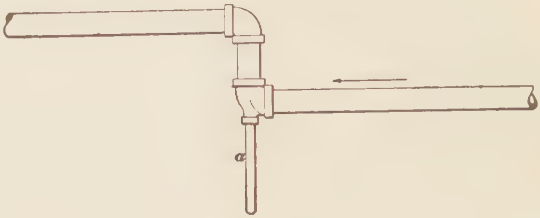


FIG. 7.

Fig. 7. A relief pipe may then be attached at the foot of each offset, as at a. The steam should always flow down grade—that is, in the direction of the arrow.

29. Riser Connections.—The riser connections in one-pipe systems may be made as shown in Fig. 8 or 9. They permit the mains to be kept from the foundation walls sufficiently to allow them to be gotten at conveniently for screwing together and also for putting on coverings, etc.

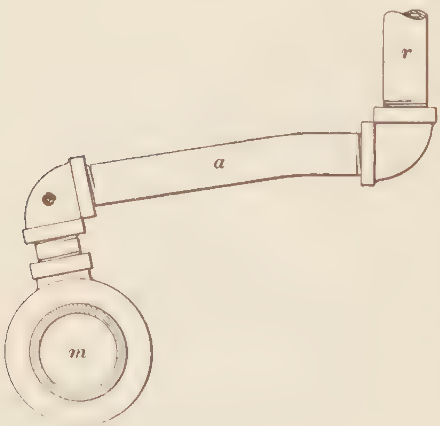


FIG. 8.

The piece a serves as a **spring piece,** and permits both the main and the riser to shift slightly by expansion. In Fig. 8 the spring piece is bent, to insure good drainage. The construction shown in Fig. 10 is sometimes used for the same purpose, the grade being secured by cutting the thread crooked at the end a. This is bad practice, because the teeth of the dies cut too deeply into the pipe on one side and weaken it seriously.

30. A riser should not be connected directly into the top of the main by a **T**, unless both pipes are very short. If the riser is long, its weight will cause the main to sag, and if the connections to the radiators above are rigid, the downward expansion will either bend the pipe or lift the radiators.

The connections to radiator branches, etc. should, if possible, be made with **Y** fittings. Plain **T** connections are objectionable in a one-pipe system, because the water of condensation runs down upon the interior surface of the riser and is very apt to flow outwards into the branch, thus increasing the difficulty of draining it properly.

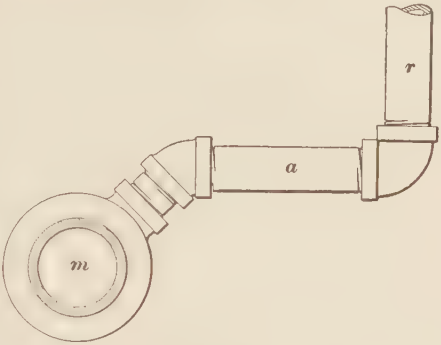


FIG. 9.

31. In the case of risers that are very high, provision must be made for expansion. This may be done by making slightly inclined offsets in the pipe, at intervals not greater than two stories apart. If the weight is considerable, the riser must be supported by other means than its connections to horizontal branches.

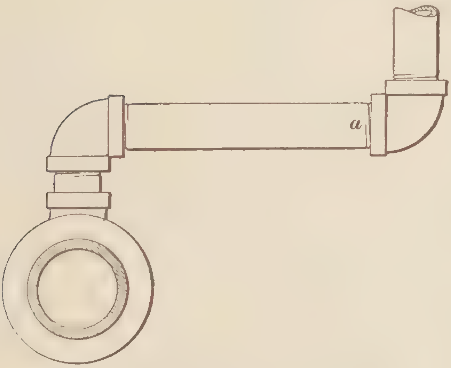


FIG. 10.

32. Radiator Connections.—The ordinary mode of connecting a direct radiator to the riser in a one-pipe system is shown in Fig. 11. The pipe *a* serves as a spring piece to allow the riser to expand without lifting the radiator

and the drop *b* insures that the water shall drain away readily.

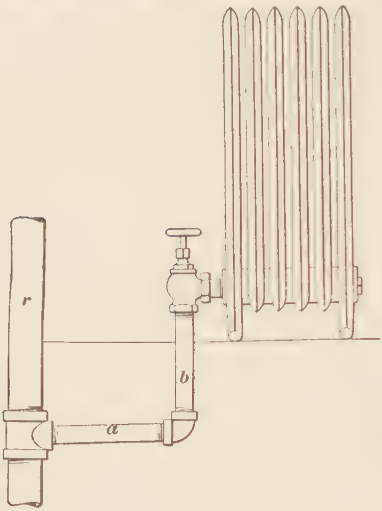


FIG. 11.

33. When the radiator is at a long distance from the riser, so that the drainage becomes difficult, it is advisable to put in a double connection, as shown in Fig. 12. The supply pipe *a* and the drain pipe *d* are both connected to the riser *r*, and a siphon is placed at *b*. All the water that flows through *a* will thus pass into the drain pipe without entering the radiator.

34. The connection shown in Fig. 13 permits the radiator to be set very close to the riser, and at the same time the spring piece *a* is so long and flexible that the riser may move considerably

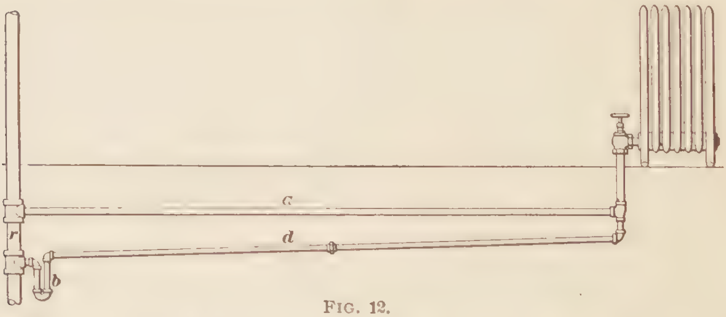


FIG. 12.

without making any trouble. It also has the advantage of being entirely above the floor, so that it is accessible at all times, and the valve is brought out into a convenient position.

35. When the vertical movement of the riser is excessive, the swivel connection shown in Fig. 14 may be used.

In this form of connection, the pipe *a* may be inclined any amount desired, in order to secure perfect drainage.

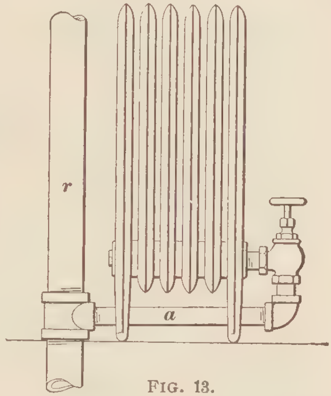


FIG. 13.

36. Returns.—The downward grade given to return pipes should be as nearly uniform as practicable. There should be no upward bends or loops, because air is likely to collect in them and impede the flow of the water. Care must be taken, also, to avoid forming sags or depressions in which water will accumulate.

When the returns are connected to a main that is located above the water level, and if there is any perceptible difference in the pressures at the various radiators thus connected, the steam will flow backwards through the return pipes towards the points of lowest pressure, and in most cases will spoil the drainage and cause water hammer. As the fall of pressure at any radiator is due solely to the resistance that the supply pipes offer the flow of steam, it follows that the trouble in that case may be remedied by increasing the diameter of the supply pipes. It is quite impracticable, however, to connect drain pipes or returns leading from radiators having a considerable difference in pressure with a dry return main.

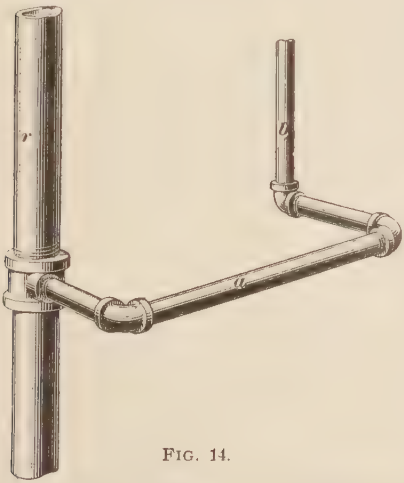


FIG. 14.

37. When the return main is located below the water level, the water that it contains acts as a barrier to prevent

the passage of steam from one return to another. Thus the steam is compelled to pass through the system in the direction it was intended to go, instead of making a short circuit or by-pass. This makes a positive circulating job.

38. Water Level in Returns.—There is always more or less difference in the pressure of the steam in the boiler and at the end of a line where the return is connected; therefore, the water will rise in the return to a height above the water level in the boiler sufficient to balance the difference in pressure. As this difference varies in the several returns, the water is likely to stand at different heights in each. The hot water rises about 29 inches for each pound of difference in pressure. If there is a water pocket anywhere in the return pipe, the water will back from it towards the radiator until it balances the difference in pressure upon the opposite sides of the water. Thus a radiator that is well above the proper water-line may be flooded with back water if there is a water pocket near it in the return.

39. Size of Pipe Required.—The proper size of pipe is one that will furnish a sufficient amount of steam without undue fall of pressure, and at the same time will not present an unnecessary amount of surface for condensation.

It is found in practice, when steam having a pressure less than 5 pounds is used, that the proper sizes for *branches* to radiators are about as follows:

TABLE I.

PROPER SIZES OF BRANCH PIPES FOR ONE-PIPE SYSTEM.

Heating Surface of Radiators.	Diameter of Pipe. Inches.
24 square feet or less........................	1
Above 24 and not exceeding 60 square feet.....	$1\frac{1}{4}$
Above 60 and not exceeding 100 square feet....	$1\frac{1}{2}$
Above 100 square feet........................	2

TABLE II.

PROPER SIZES OF BRANCH PIPES FOR TWO-PIPE SYSTEM.

Heating Surface of Radiators.	Diameter of Steam Pipe. Inches.	Diameter of Return Pipe. Inches.
48 square feet or less..................	1	$\frac{3}{4}$
Above 48 and not exceeding 96 square feet	$1\frac{1}{4}$	1
Above 96 square feet	$1\frac{1}{2}$	$1\frac{1}{4}$

40. These data are for *direct* radiators, and if indirect radiators, which condense more steam per square foot, are used, the size of the pipes should be increased. The proper sizes are given in the following table:

TABLE III.

PROPER SIZES OF BRANCH PIPES FOR SYSTEMS WITH INDIRECT RADIATORS.

Heating Surface of Indirect Radiators.	Diameter of Steam Pipe. Inches.	Diameter of Return Pipe. Inches.
30 square feet or less....................	1	$\frac{3}{4}$
Above 30 and not exceeding 50 square feet	$1\frac{1}{4}$	1
Above 50 and not exceeding 100 square feet	$1\frac{1}{2}$	$1\frac{1}{4}$
Above 100 and not exceeding 160 square feet	2	$1\frac{1}{2}$

41. The size of steam mains or of principal risers may be computed by the following rule:

Rule 1.—*Divide the amount of direct heating surface in square feet by 100; divide the quotient by .7854; then extract the square root of the quotient; the result will be the diameter of the pipe in inches.*

EXAMPLE.—What diameter of main steam pipe is required to supply direct radiators having a total heating surface of 3,800 square feet?

SOLUTION.— $\sqrt{\frac{3,800}{100} \div .7854} = 6.9$ inches; or, in practice, 7-inch pipe. Ans.

42. To find the amount of radiator surface that may be properly supplied by any given size of pipe, the reverse process should be followed:

Rule 2.—*Multiply the square of the diameter of the pipe in inches by .7854; then multiply the result by 100; the result is the total amount of heating surface in square feet which the pipe will supply.*

EXAMPLE.—What amount of direct heating surface may be supplied by a steam pipe 7 inches in diameter?

SOLUTION.— $7^2 \times .7854 \times 100 = 3,848$ sq. ft. nearly. Ans.

43. Expansion Pieces.—The iron pipes that are used in steam fitting expand about $1\frac{1}{2}$ inches per hundred feet in length. In long lines of pipe this expansion must be provided for, otherwise it will make trouble by breaking connections or shoving apparatus out of place. In large pipes the expansion may be taken up by means of an ordinary expansion sliding joint.

These sliding joints are generally objectionable because of the care required to keep the packing tight and in good order. The sliding tube should be made of brass or bronze, to prevent its corroding and sticking fast.

44. Other modes of providing for the linear expansion of pipe, especially in the smaller sizes, are shown in Figs. 15 to 18. In Fig. 15 an offset is made in the pipe, and the piece *a*, which is called a **spring piece**, is made long enough to bend or spring sufficiently to permit the necessary

movement of the pipes *b*, *c* without straining the threads excessively or cracking the fittings.

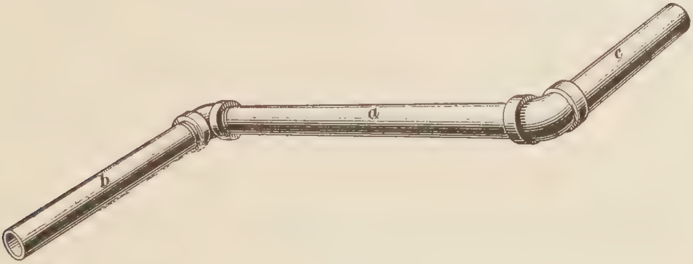


FIG. 15.

45. In Fig. 16 the spring piece *a* is bent into a **loop,** as

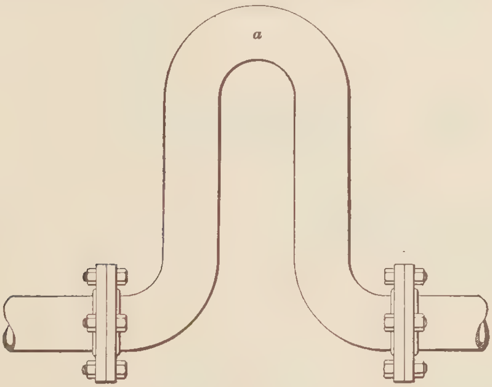


FIG. 16.

shown. Pipes of this kind are usually made of copper, with brass flanges brazed on.

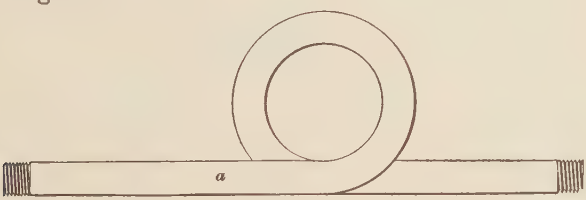


FIG. 17.

46. In Fig. 17 the pipe *a* is bent into a **coil.** This form affords such an easy bend that ordinary wrought-iron pipe

may be used without difficulty. The diameter of the circle should be large enough to spring the desired amount without serious straining.

Care must be taken in using the devices shown in Figs. 16 and 17 to avoid forming a pocket in which water or air may collect. A pocket may usually be prevented by extending the loop or coil horizontally instead of vertically.

47. In Fig. 18 the connections are made so as to **swivel** instead of bend. When the pipes *b* move endwise by expan-

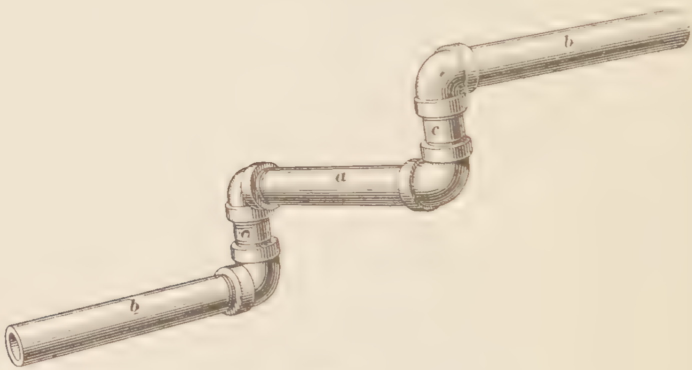


Fig. 18.

sion, the nipples *c* turn slightly in their threads and thus permit the piece *a* to swing to the requisite extent.

48. During the erection of a steam-heating plant, the matter of expansion must be carefully considered. The best point for fastening each principal pipe so that its expansion will cause the least disturbance should be determined by close examination. Care must be taken to have every such pipe *free* at its ends and to see that its connections or branches are not bound or rendered immovable by plaster, brick, wood, or iron beams or columns. The pipe fitter should personally inspect every such point and make sure that the pipe system is free to expand before steam is turned on.

49. Special Fittings.—Fig. 19 shows a fitting designed to make a connection between a radiator branch and a continuous riser. The partition *a* is curved so as to secure a proper supply to the radiator, and the passage *b* permits the main current to ascend without excessive obstruction. It is intended to take the place of the common fittings shown in Fig. 21 that are usually employed for the same purpose, and it also has the advantage of preserving the alinement of the parts of the riser. Fig. 20 is a variety of **T Y** which is designed for the same or similar use as Fig. 19.

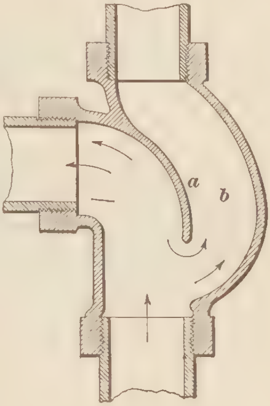


FIG. 19.

50. Fig. 22 shows an **eccentric reducer,** which serves to bring the bottoms of the connected pipes to the same level and thus prevents the lodgment of water at that point. This is particularly useful on steam mains and other nearly horizontal steam pipes.

51. Fig. 23 is a **cross,** or double **T,** having the branches at a higher level

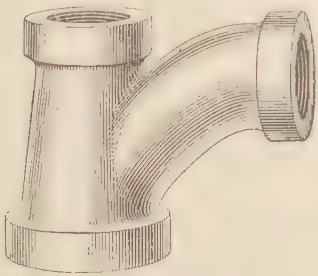


FIG. 20.

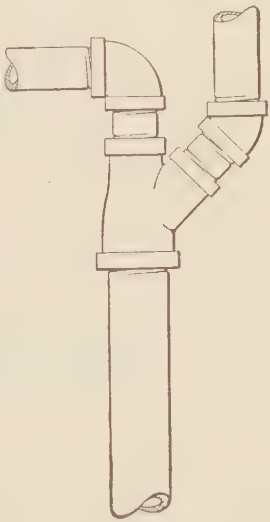


FIG. 21.

than the main pipe. This form of connection insures the proper drainage of the branches into the main steam pipe

and also prevents the water of condensation in the bottom of the main entering the branches.

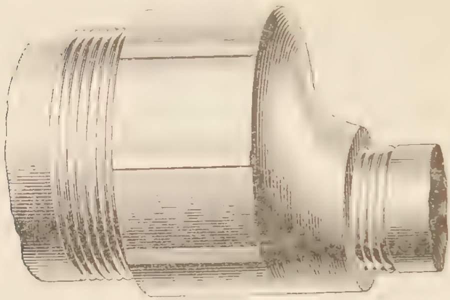


FIG. 22

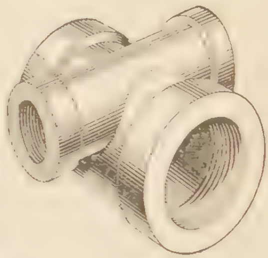


FIG. 23.

PIPING A BUILDING.

52. Method of Procedure.—New buildings are piped while the work of construction proceeds, as soon as the walls are up and the roof is on. On large jobs the risers are usually put up first, next the horizontal branches are constructed, proceeding always from the riser towards the radiators, and lastly the mains are put in place. The returns are constructed at the same time and in a similar manner.

In many cases, however, particularly in small buildings, the mains are run in first, then the risers, and finally the radiator connections. This latter method avoids the use of "right and left" fittings, or unions, between the risers and the mains.

All radiator connections should be promptly **capped** as soon as erected, and all openings in T's and other fittings should be plugged at once, so that no dirt may get into the pipes.

53. Testing.—The piping should be tested for tightness before it is covered by plaster or flooring, so that if any defective fittings or split pipes are discovered, they may be replaced without trouble. The testing is done by filling the system full of water, every opening being tightly

closed, and then applying pressure by means of a force pump. The pressure is increased until the gauge shows from 100 to 150 pounds per square inch. Another test should be made with steam before the pipes are covered, if possible. This will determine whether the expansion is properly provided for and whether the system is in working order. The steam pressure used should not greatly exceed the proposed working pressure.

54. Clearance.—All steam pipes should be kept out of contact with woodwork or other combustible materials. A clearance of at least 2 inches should be maintained at all points, and where this cannot be had, special protection should be provided. Return pipes are liable to be full of hot steam at times, therefore they must be guarded the same as steam-supply pipes.

55. Floor and Ceiling Flanges.—Fig. 24 shows the manner of using floor and ceiling flanges to protect the

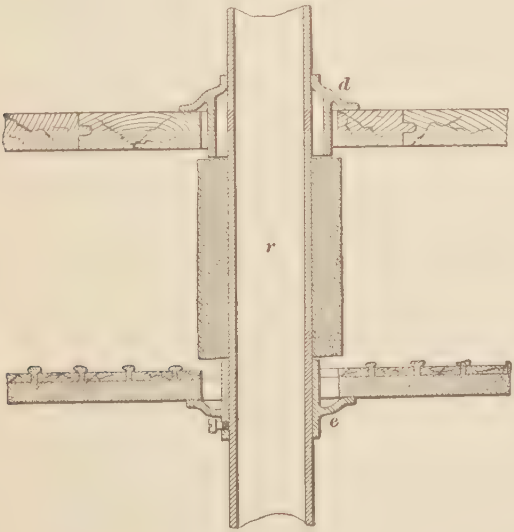


FIG. 24.

woodwork where a steam pipe passes through an ordinary floor. When the ceiling flange *e* is secured to the pipe by a

setscrew, as shown, allowance must be made in setting it for the vertical expansion of the pipe, otherwise it will be liable to break the plaster forming the ceiling when the steam is turned on; or the ceiling flanges may be secured after the steam is on. A better construction is to connect the upper and lower flanges by a nipple a size or two larger than the riser, and have a current of air flowing through the spaces between the pipes and any combustible material.

EXHAUST AND VACUUM SYSTEMS.

EXHAUST SYSTEM.

56. Saving Effected.—The exhaust system is in every respect a low-pressure system, except that it is provided with special apparatus that adapts it to receive the exhaust steam from engines and pumps. It is used only for the purpose of utilizing and saving the heat in exhaust steam that would otherwise go to waste.

The magnitude of this waste may be easily seen when it is considered that exhaust steam at 5 pounds gauge pressure contains 971 British thermal units per pound that are available for heating, and if not thus used, would be discharged through the exhaust pipe into the atmosphere.

The practice of allowing exhaust steam to escape into the atmosphere in any situation where it can be used in heating apparatus, either for housewarming or heating liquids, etc., is, therefore, inexcusably wasteful.

57. General Arrangement.—The general arrangement of apparatus for controlling the steam supply and drainage in an exhaust system is shown in Fig. 25. The steam-heating main *a* is connected to the exhaust pipe *b* and also to a pipe *c* that supplies live steam from the boilers. This steam passes through a pressure-reducing valve *e* and is lowered in pressure to the desired amount before entering the heating main. By this arrangement the heating system will be supplied with exhaust steam as long as the engines

are in operation, but if for any reason the supply becomes insufficient to maintain the proper pressure, then live steam will enter through the reducing valve and make up the deficiency. If the supply of exhaust steam becomes excessive, so that the pressure rises unduly, the excess will escape by opening the back-pressure valve *f* and blowing into the

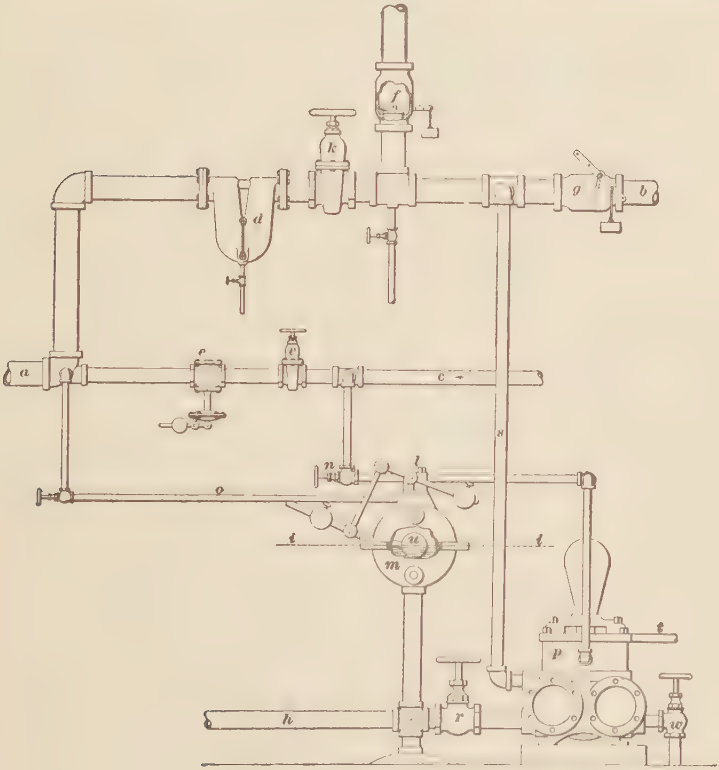


FIG. 25.

atmosphere. When the engines are stopped, the steam in the heating apparatus is prevented from passing backwards and filling them with water by means of the check-valve *g*. This valve is similar to the valve *f* in construction and is so nearly balanced by its counterweight that it will open very easily. The relief valve *f* is usually adjusted to

blow off at a pressure about 1 pound higher than that maintained by the reducing valve *e*.

The exhaust steam is passed through a separator *d* before entering the heating system, for the purpose of removing the entrained water, and especially for removing the oil that accompanies it from the engine.

58. Disposal of Drainage.—The drainage from the heating apparatus is collected in the pipe *h* and is returned to the boiler by means of a pump *p*, as shown. The returns have no direct connection with the boiler, consequently the water level in them may be maintained at any convenient height, as at *i i*. This is accomplished by means of the pump and its governor *m*. The **pump governor** is merely a closed vessel containing a float *u* that rises and falls with the water level. The steam that drives the pump is taken from the high-pressure pipe *c* through the stop-valve *n* and passes through a throttle valve *l* that is controlled by the float. When the water rises above the desired level, the float opens the throttle and starts the pump; when it subsides, the float is lowered and shuts off the steam. The exhaust from the pump is turned into the exhaust main through the pipe *s*. The pump governor is connected to the heating main *a* by a small pipe *o* for the purpose of equalizing the pressure on top of the water therein.

59. Location of Valves.—Valves are provided in the main pipes, at *k* and *v*, for the purpose of shutting off the heating apparatus during the summer season. It will be noted that these valves are located so that they do not interfere with the supply of steam to the pump nor with the exhaust therefrom. The returns are shut from the pump by the valve *r*, and an independent water supply is attached at *w*. The pump delivers through the pipe *t* to the boiler.

60. Care must be taken to locate the valves *f* and *g* in proper relation to each other, as shown. If the check-valve is placed between the heating main *a* and the valve *f* and the reducing valve *e* should get out of order, the pressure

would rise in the heating system until it equalled that in the boiler. This would probably burst the radiators and do serious damage. The safety of the whole apparatus depends on the good working condition of the relief valve *f*.

VACUUM SYSTEM.

61. General Description.—The **vacuum system** of steam heating differs from all others in one important particular, which is, that a vacuum, more or less perfect, is constantly maintained in the returns. This permits the system to be operated with steam of any convenient pressure, high or low, and from any source, either exhaust or otherwise. The pressure and temperature throughout the whole system may be adjusted and maintained at any degree between full-boiler pressure and a low vacuum, thus making the system adjustable to suit all conditions of weather and service.

Generally the system is operated with exhaust steam, the supply being arranged as shown in Fig. 25. The piping is usually arranged on the two-pipe system, and the returns are generally made independent, although it is not necessary to do so in all cases.

62. Essential Features.—Fig. 26 shows the essential features of the system. The returns *a*, *a* are connected to a receiver *b*, which collects all the air and water in the system. These are pumped out by means of the **vacuum pump** *v*, which thus maintains a constant vacuum of any degree desired in the returns.

By this arrangement any steam may be used in the radiators that is warm enough to operate the traps or "thermostatic valves" that are placed on the return end of each radiator to open automatically when water or air is required to pass through, but to close when steam begins to pass through. This prevents the returns from becoming filled with steam. The vacuum system permits steam to be used at a pressure far below that of the atmosphere and at any temperature down to about 140°, the limit being fixed only

by the ability of the pump to keep up the vacuum in the returns.

63. There are various forms of exhausting apparatus that may be used in place of the pump, to maintain the vacuum, such as "injector condensers," etc., but as they are not an essential part of this system, they will not be described here.

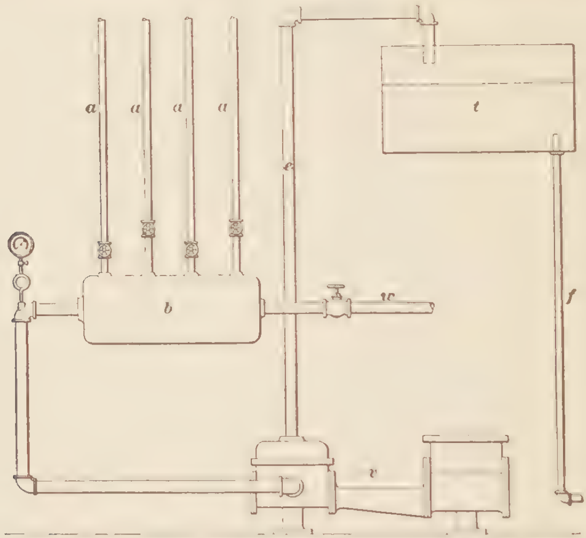


FIG. 26.

The water and air that are drawn from the receiver by the vacuum pump are discharged into an open tank, from which the air readily escapes. The water is then pumped back into the boiler by any ordinary feed-pump.

64. In some cases, the fresh, cold water, which is otherwise required to feed the boilers, is injected into the receiver in a series of fine streams through the pipe *w*, the object being to condense as much as possible of the steam that may be present and thus improve the vacuum. At the same time that the water becomes warmed it gives up the air accompanying it, thus increasing the amount to be removed by the pump. This air expands into the vacuum and partially neutralizes the effect of the condensation. Thus it will be

seen that the introduction of the feedwater into the system at this point is of doubtful utility. If it is sent through an ordinary feedwater heater instead, it will become much hotter and the air will be eliminated without difficulty.

65. Advantages.—It will be understood that when the exhaust steam from an engine is turned into the ordinary low-pressure heating system, the back pressure is increased, and the efficiency of the engine is correspondingly decreased, sometimes to such an extent as to become very detrimental.

One of the principal advantages of the vacuum system is that a great part of the back pressure is taken off the engines, and the capacity of the engines to do useful work is thereby increased.

The size of the piping required for the vacuum system of steam heating is about the same as for the ordinary low-pressure system. The volume of the steam required is greater, owing to the low pressure, and the amount of heat per cubic foot is correspondingly less than that found in ordinary heating systems, but the difference between the pressures of the steam in the supply pipes and in the returns is so great that the volume of steam necessary to carry the amount of heat required is driven through the pipes without difficulty.

The radiators, however, must be larger than for any other system, in proportion as the temperature of the steam used is lower.

DISTRICT SYSTEM.

66. The **district system** of steam heating is practiced in large towns and cities by means of steam mains that are laid underground through the streets. The arrangement of the connections from the street mains to the house pipes is shown in Fig. 27. The service pipe *a* is provided with a valve *b* inside the basement wall, so that the house system can be shut off when desired. The steam passes through a pressure-reducing valve *c* and thence into the distributing pipe or house main *e*. The water that may enter from the service pipe is led away by the drain pipe *d*. The returns

are all connected into the pipe *f*, which is submerged below the water level. The level of the water in the returns is fixed by the elevation given the steam trap *t*; thus, in the figure, it is at the line *g*. The hot water from the trap should never be discharged directly into the house drains, because of its destructive effect upon the pipes, but should be cooled before escaping to the sewers, by first allowing it to flow through a coil of pipes. This coil is usually called a

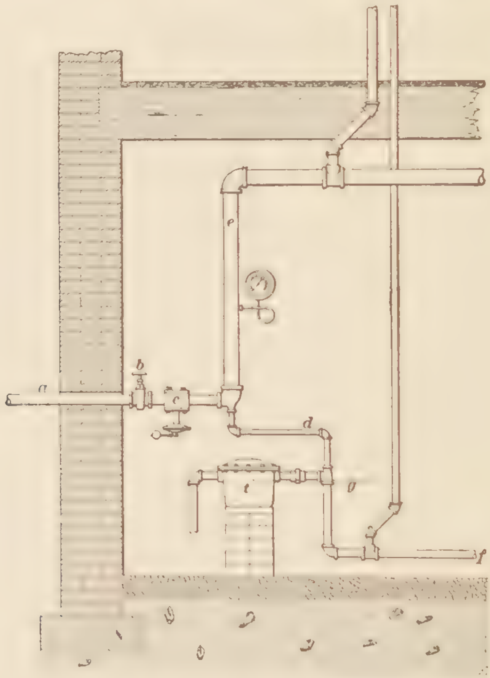


FIG. 27.

"cooling coil." It should never deliver directly into the drainage system, but in all cases should deliver into a deep, sealed trap. This is to prevent drain air entering the heating system or the building. The trap, or hotwell, should always deliver into the house-sewer connection on the sewer side of the main-drain trap, to prevent hot vapors passing up the iron drainage system in the building.

HEATING SYSTEM DETAILS.

AIR VENTS AND TRAPS.

67. Air Vents.—All automatic air vents on steam-heating systems are *thermostatic* in principle; that is, they are controlled by a difference in temperature between the steam and the air that is to be expelled from the heating apparatus.

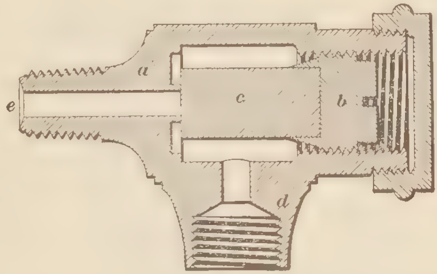


FIG. 28.

Fig. 28 shows the construction of an ordinary air vent. The shank *a* is screwed into a radiator tube and the nozzle *d* is connected to a suitable drip pipe. The valve *c* is a rod composed of some expansible material that is adjusted against the steam orifice by means of the screw *b*. When air enters the orifice *e* instead of steam, the rod *c* cools and shortens slightly, thus opening the orifice and permitting the air to flow through. As soon as hot steam arrives, however, the rod expands and again closes the vent.

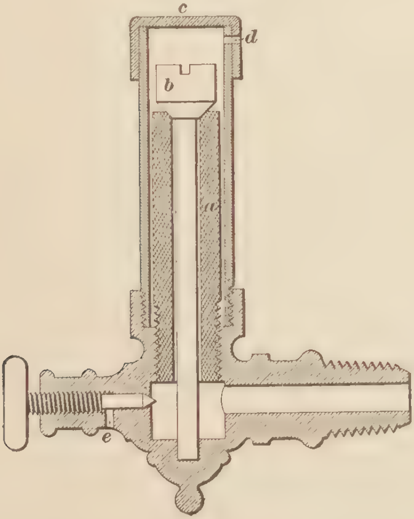


FIG. 29.

68. The length of the expansible element that is exposed to the air or steam is very small, consequently the opening of the vent will be very slight and quite slow in operation. This is improved in the construction shown in

Fig. 29. The expansible rod *a* is much longer and is hollow. Its whole interior surface is exposed to the steam or air at all times. The lower end is screwed fast to the body of the vent and the upper end draws away from the valve *b* when contraction occurs from the cooling influence of air. The valve *b* has a long stem that screws into the bottom of the chamber, and it is easily adjusted by means of a screw-driver when the cap *c* is removed. The air passes through the vent hole *d*. A small screw valve *e* is added for relief by hand when desired.

Both of the devices shown will permit the escape of water as readily as air, therefore they should be provided with suitable drip pipes. Otherwise, they are very liable to discharge water at almost any time and thus make serious trouble.

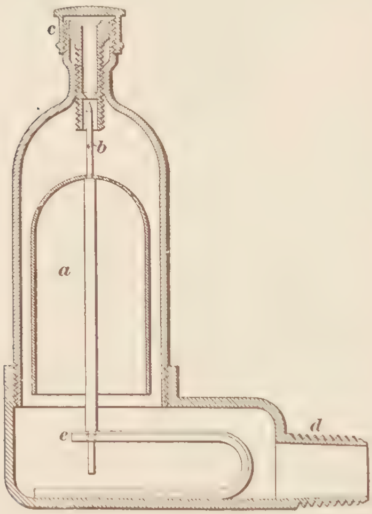


FIG. 30.

69. In Fig. 30 the trouble mentioned in Art. **68** is remedied by attaching a cup or float *a* to the stem of the air valve *b*. This stem rests loosely on the bent spring *e*, and when the chamber fills with water, the float will lift the valve and close the vent. The valve is opened to discharge air by the bending of the spring, which is made of two strips of different metals firmly soldered together. These contract by different amounts when cooled, thus bending the spring and allowing the valve to open slightly.

70. The proper place to attach an air vent to a radiator or coil is at a point as far as practicable from the steam inlet, so as to prevent the current that moves towards the

vent carrying hot steam to it and thus closing it before all the air has escaped.

71. Return Traps.—Return traps are used only for returning the water of condensation to the boiler. It is immaterial whether the pressure in the boiler greatly exceeds that in the heating apparatus or not; they are equally serviceable for all cases. They require to be set above the water level in the boiler, at a sufficient elevation to allow the water to flow from them into the boiler by gravity.

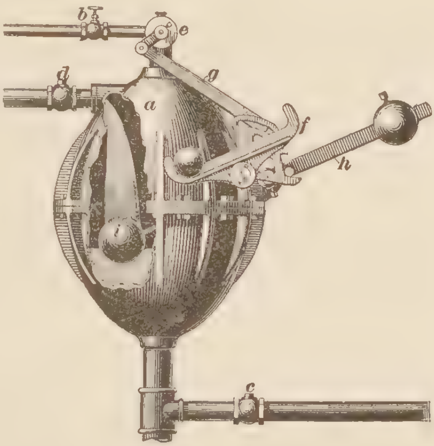


FIG. 31.

72. Fig. 31 shows a very common form of a return trap. It is composed of a globe *a* that performs the duty of a condenser and receiver, and the connecting pipes on which are attached the valve *b* and check-valves *c* and *d*. The pipe on which *c* is placed joins the boiler, usually below the water-line, and the pipe on which *d* is placed joins a receiver that is set at the lowest ends of the return mains to receive water of condensation from the heating system.

The pipe on which *b* is placed joins the steam space of the boiler. A rotary slide valve *e* engages with a rocking casting *f* by means of a connecting link *g*, the engaging point between *f* and *g* being provided with slack motion, as shown.

A lever *h* having a float *i* on one end (inside the trap) and a counterpoise weight on the other end also engages with the casting *f* by a slack-motion connection, as shown.

A track is formed in the casting *f* along which the solid ball shown may roll.

73. The action of the trap is as follows: When a vacuum has been formed in the globe *a* by the condensation of steam, water of condensation from the receiver will flow through *d* and into the trap, as shown, and will continue flowing until the trap is full or the receiver empty, providing the trap is not set too high. As the water rises in the trap, the float *i* will rise with it and the loaded end of the lever *h* will descend correspondingly. As this movement of *h* continues, the stud that engages *h* with the casting *f* pushes down that end of *f*, thereby bringing the track nearer a level position. This it does without moving the rotary valve *e* on the steam connection, because of the slack motion between *g* and *f*.

As soon as the end of the track on which the ball rests is raised above the level of the other end, the ball will roll along the track, strike the opposite hooked end, and cause it to fall rapidly, opening the steam valve *e* to its full extent. At this point, the trap is about full of water, and since the full boiler pressure is now placed on the surface of the water in *a* and since this water is higher than that in the boiler, it will be easily seen that the water in *a* will simply fall by gravity into the boiler.

As the water drains from *a*, the float *i* will descend, and when it has reached the bottom of the globe, the track will be tilted in the opposite direction by the ball, when the steam valve *e* will be suddenly closed and the trap will be prepared to receive another charge from the heating system as the steam condenses in the globe.

74. The height to which water can be lifted is limited by the difference between the pressure in the receiver and the vacuum formed in the trap. As nearly all varieties of return traps depend on the formation of a vacuum in order to become filled with water, it is essential that air be carefully excluded from them.

RADIATORS AND COILS.

75. Form of Heating Surfaces.—Heating surfaces, i. e., the exterior surfaces of radiators and coils, that have no projections of any kind are classified as **plain surfaces,** while those having ribs, knobs, pins, or other projecting parts are called **extended surfaces.**

The object sought in the construction of extended surfaces is to make the area of the emitting surface greater than that of the absorbing surface. By this means heat may be transferred from a fluid that gives it off readily to one that takes it up slowly with but little decrease in temperature of the heat-transmitting surfaces.

A plate having extended surfaces will emit more heat per hour than the same plate without the extensions, but less than a plain plate having the same actual area of exposed surface.

Extended surfaces have no advantage over plain surfaces unless the velocity of the air passing over them is sufficient to sweep them clean of hot air as rapidly as it is formed. When air is moved wholly by convection, as is the case when a radiator stands in still air, the plain surfaces clear themselves of hot air better than do the extended surfaces and are, therefore, more effective.

76. Efficiency of Radiators.—The efficiency of a heater or radiator will increase as the velocity of air passing over it is increased, but not in the same proportion. With increased velocity, the duration of contact of air with the hot surface is shortened and the rise of temperature will be less, but the quantity of air heated will be increased so much that the total heat given off from the radiator per square foot of surface per hour will be increased.

77. Arrangement of Heating Surfaces.—The efficiency of a radiator will depend, to a considerable extent, on the direction in which the air is moved over the heating surfaces. Fig. 32 shows a vertical tube standing in still air. The tube is heated by steam and its surface has a

temperature that is practically uniform throughout. The air, which is warmed at the lower end of the tube, flows upwards and envelops the upper part in a current of hot air. The emission of heat will be slower from the upper part of the tube than from the lower part, because the difference in temperature between the air and metal is less.

FIG. 32.

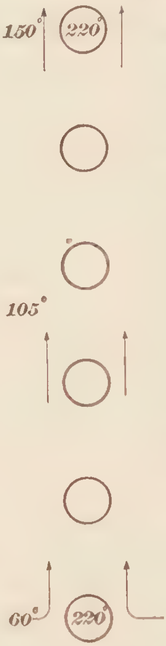


FIG. 33.

The temperature at the various points is marked on the sketch.

A similar loss of efficiency occurs in a common coil of horizontal pipes laid vertically over one another, as shown in Fig. 33. The upper pipes are enveloped in the warm air that has been heated by the lower pipes.

78. The maximum efficiency can be attained by placing the coil or radiator in a horizontal position, as indicated in Fig. 34. Each tube will then operate upon air of equally low temperature, and, consequently, the rate of emission will be

FIG. 34.

greater than in the cases shown in Figs. 32 and 33.

79. If radiator tubes are grouped together in large numbers, as in Fig. 35, the efficiency of the tubes in the interior of the group will be much less than that of the outside tubes, because the access of cold air to them is practically cut off, and they can act only on air that has already been warmed by the outer tubes.

Their efficiency is still further reduced by the fact that nearly all the heat that they emit by radiation is intercepted and cut off by the outer tubes.

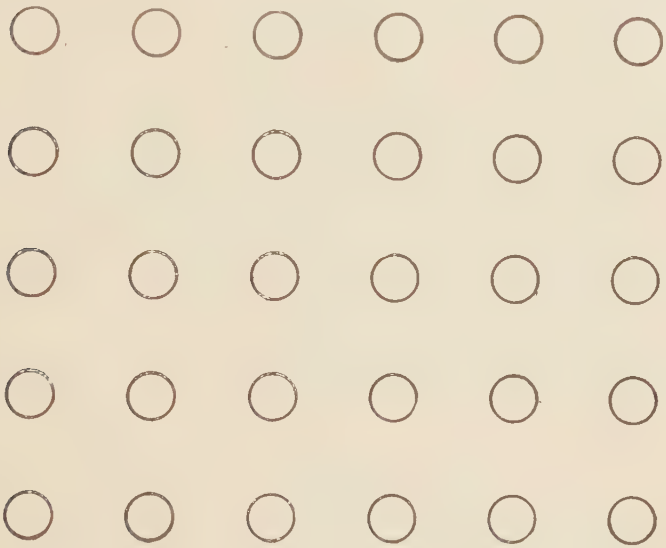


FIG. 35.

Therefore, the most effective form of radiator or coil for direct heating is one having only a single row of tubes.

80. Flue Radiators.—Figs. 36 and 37 show varieties of radiator tubes that are so shaped that, when they are assembled in a group, they enclose vertical air flues as shown at *a*. The bases of the tubes are set high enough above the floor to permit an abundant flow of air into the flues at the bottom. Radiators constructed in this manner are called **flue radiators.**

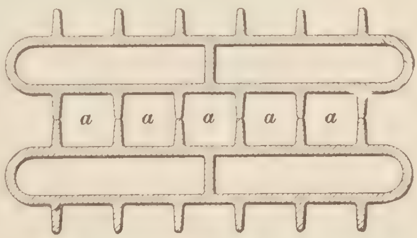


FIG. 36.

The advantages of this construction are that the interior parts of the radiator are fairly well supplied with air and that the flues impart a higher velocity to the air than it would otherwise obtain. The emissive capacity of the two forms shown in Figs. 36 and 37 will differ greatly with the relative amount of plain and extended heating surfaces that they afford, and also with the proportion of heating surface to the area of the flues.

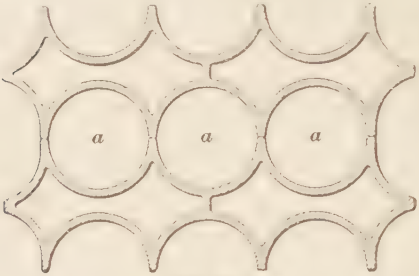


FIG. 37.

81. Continuous Flat Coil.—The continuous flat coil, Fig. 38, is made of straight pipe connected by return bends.

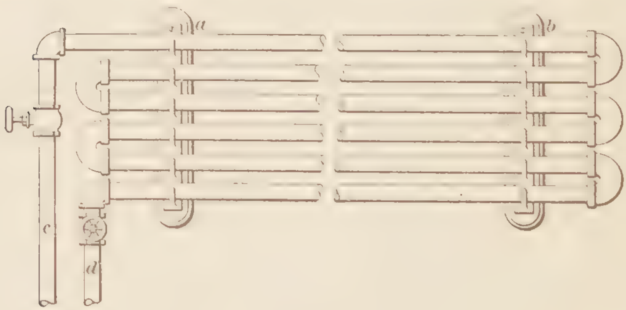


FIG. 38.

The circulation of the fluid through it is direct and certain, and it is regarded as the most efficient form of radiator in common use.

82. Miter Coil.—A miter coil is shown in Fig. 39, the pipes being connected between two manifolds *a* and *b*. The steam moves forwards simultaneously through all the pipes; therefore, its velocity will be one-sixth the rate in a single

pipe, as in Fig. 38. The circulation is likely to be uneven, because the fluid entering at *g* will naturally, owing to its momentum, flow to the end of the manifold, and so a greater quantity will enter the pipe *e* than pipe *f*. The path through *e c* is shorter than through *f d*, and, the friction being less, the main part of the current will go that way.

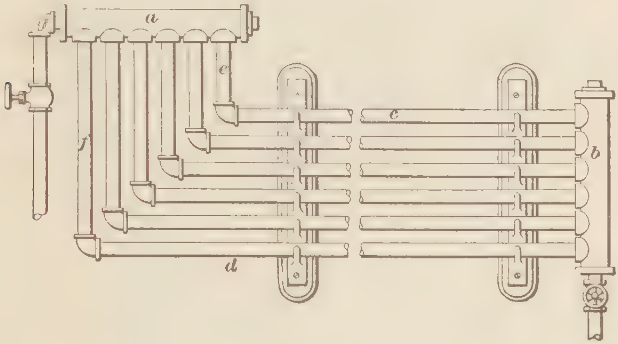


Fig. 39.

It will be noted that all the horizontal pipes are connected to the manifold *a* by means of elbows and vertical pipes. This must always be done, so as to permit the several pipes to expand independently, as their varying temperatures may require. The vertical pipes will bend or yield sufficiently to accommodate the difference in expansion.

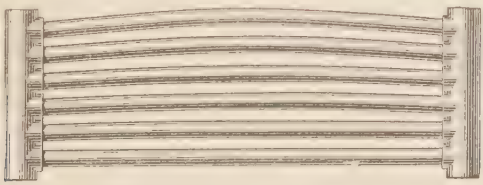


Fig. 40.

83. Manifold Coil. If a coil is made by connecting two manifolds, as in Fig. 40, it will be difficult to keep it steam-tight. The upper pipes will expand more than the lower

ones, and they will either bulge and spring, as shown, or they will crack or break some of the connections.

84. Box Coil.—When several flat coils are grouped together, as shown in Fig. 41, the construction is called a **box coil.**

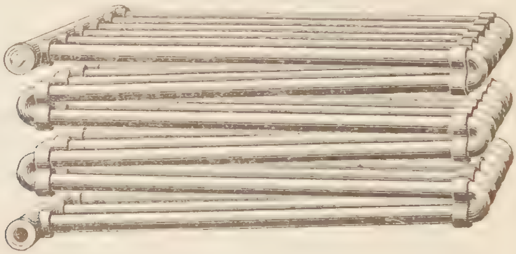


FIG. 41.

The spring pieces of a coil should be put together with right-and-left screw joints, so that the coil may be readily disconnected at any time and without unnecessary labor.

85. Size of Pipe for Coils.—The size of pipe used for constructing coils depends chiefly on the pressure of steam to be used, the length of the coil, and the force of the circulation through it. A coil like Fig. 39 could be made of smaller pipe than one like Fig. 38, because the current of heating fluid is diffused throughout the whole series instead of passing entirely through each pipe. The difference, however, would seldom exceed one or two sizes of pipe. The customary size of pipe used is from 1 inch to $1\frac{1}{2}$ inches—the latter being used for exhaust-steam heating.

Pipe coils must be arranged so that all water that is condensed within them may flow easily towards their outlets.

86. Nason Tube.—Fig. 42 shows a tube called the **Nason tube.** It is connected to the radiator base by a single screw joint and is divided into two passages by means of a sheet-iron plate *a* that extends nearly to the

top of the tube, as shown. The steam rises on one side, passes over the end of the plate, and descends on the opposite side of the tube. Each tube thus forms a complete *loop*, or circuit.

87. Bundy Loop:—Fig. 43 shows the Bundy loop, in longitudinal section at *A* and cross-section at *B*. This, also, is screwed into a cast-iron radiator base of suitable shape, and the steam moves up one branch of the tube and down the other.

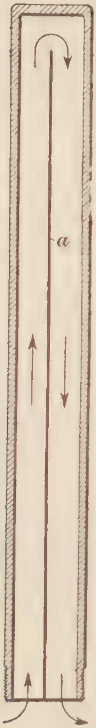
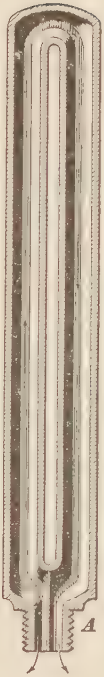


FIG. 42.



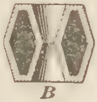


FIG. 43.

88. Detroit Loop.—The Detroit loop is shown in Fig. 44. Each loop is complete in itself and requires no base or supply chamber. The loops are connected together, in any number desired, by means of nipples *a* and *c*. When the connection at the top is not desired, the loops are bound

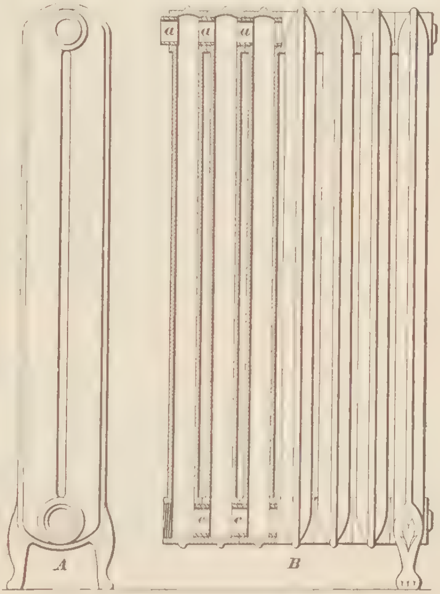


FIG. 44.

together by a bolt that passes through the space between them, shown in the end view.

The construction of this class of loops is often varied so that they comprise three or even four parallel tubes. They are also modified so as to form flue radiators.

89. Pin Radiator.—Fig. 45 shows an extended-surface indirect radiator that is in extensive use for indirect heating.

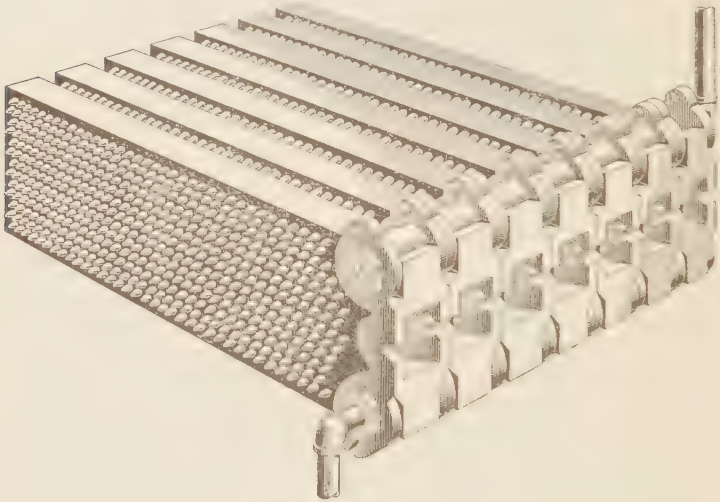


FIG. 45.

It is called a **pin radiator** because the extensions of the heating surface are made in the shape of small conical pins. The air flows up between the sections and impinges against the pins.

90. Forced-draft heaters, which are commonly used for heating air on a large scale, where forced draft is used, are constructed in a manner similar to that shown in Fig. 46; (*b*) is an elevation and (*a*) a plan. The tubes are of 1-inch steel or wrought-iron pipe and are connected at the top by

cross pipes instead of return bends, thus preventing all distortion by unequal expansion.

The tubes are *staggered*, so that those in one row stand opposite the spaces between the tubes in the preceding row.

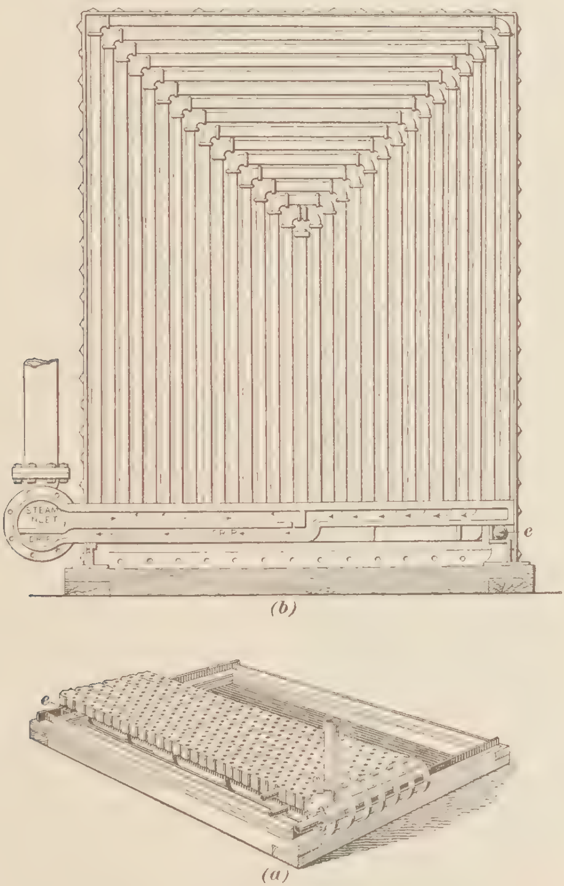


Fig. 46.

By this means, all parts of the air-current (which passes through horizontally) are brought into contact with the tubes and thoroughly heated.

The *base sections*, or *headers*, are coupled together at one end by flanged joints. The group of base sections may be divided into two or more parts, each of which may have an independent supply and return pipe. Thus, the whole heater may be used or only a part of it, as desired. The sides of the sections are corrugated so that they interlock and leave no open spaces between them. The farther end of each section rests upon a roller *e*, so that they can expand and contract freely without straining. The course of the steam through the heater is shown by the arrows.

91. The ordinary varieties of vertical-tube radiators may easily be adapted to direct-indirect heating. The mode of applying a direct radiator of the Nason or Bundy type to that purpose is shown in Fig. 47. The base of the radiator is enclosed by plates *a*, so that the fresh air, which comes in through the tube *b*, is compelled to pass upwards and between the hot tubes before it can escape into the room.

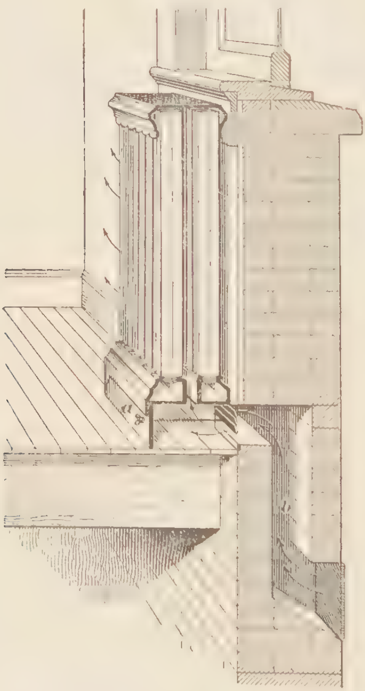


FIG. 47.

92. Proportioning Radiation Surface.—To correctly determine the amount of radiation required to properly warm a given space requires the best judgment of a heating engineer. A number of rules and formulas for determining radiation are in use; some are simple and some are complicated. The following table gives the allowance of heating surface commonly supplied for ordinary purposes:

TABLE IV.

TABLE FOR PROPORTIONING RADIATION SURFACE TO CUBICAL CONTENTS OF ROOM TO BE WARMED.

Space to be Heated.	Allowance of
Bathrooms and living rooms with three exposed walls and a large amount of glass surface	1 square foot for each 40 cubic feet.
Bathrooms and living rooms with two exposed walls and large amount of glass surface	1 square foot for each 50 cubic feet.
Bathrooms and living rooms with one exposed wall and ordinary amount of glass surface	1 square foot for each 60 cubic feet.
Sleeping rooms	1 square foot for each 60 to 70 cubic feet.
Halls	1 square foot for each 50 to 70 cubic feet.
School rooms	1 square foot for each 60 to 80 cubic feet.
Churches and auditoriums having large cubical contents and high ceilings	1 square foot for each 65 to 100 cubic feet.
Lofts, workshops, and factories	1 square foot for each 75 to 150 cubic feet.

The foregoing simple table applies to direct radiation only. If indirect radiators are used, allow not less than 50 per cent. more surface. If direct-indirect radiators are used, allow not less than 25 per cent. more surface. In estimating radiation, make ample allowance for exposure of building, materials of construction, and loose doors and windows.

93. We do not recommend the general use of any method of proportioning radiation to the cubical contents of the rooms to be heated. The foregoing is presented for the convenience of those who may be able to use it with good judgment and for "checking up" purposes.

94. One of the most simple and probably most correct empiric rules used for computing the size of direct radiators is that originated by Mr. William J. Baldwin, a well-known American heating engineer, and is as follows:

Rule 3.—"*Divide the difference between the temperature at which the room is to be kept and that of the coldest outside atmosphere by the difference between the temperature of the steam pipes and that at which you wish to keep the room, and the quotient will be the square feet, or fraction thereof, of plate or pipe surface to each square foot of glass, or its equivalent in wall surface.*"

The quantity of heating surface found by this simple rule merely compensates for the amount of heat lost by transmission through the windows, walls, and other cooling surfaces; it does not provide for cold air entering the room through loosely fitting doors, windows, etc., and an ample allowance must be made for this. Some buildings are so poorly constructed that 50 per cent. or more must be added to the amount of heating surface obtained by the above rule, in order to counteract the cooling effect of these air leakages. A common practice is to add 25 per cent. for buildings of ordinarily good construction. Besides this addition for air leakage, an ample allowance should be made for rooms exposed to cold winds, and this allowance should, if possible, be made in the form of an auxiliary radiator to prevent overheating the rooms during moderate weather.

95. Suppose that we have three rooms A, B, and C, as shown in Fig. 18, of precisely the same dimensions, and, consequently, having the same cubical contents, the rooms being each 25 feet long by 20 feet wide, with a 10-foot ceiling.

Let us also suppose that the halls, or corridors, D and the other rooms in the building will be warmed to a temperature equal to that desired in A, B, and C by other radiators not shown; first proceed to find, by rule **3**, Art. **94**, the amount of heating surface required to maintain a temperature of 70° F. in A, B, and C, assuming that the radiators will be

heated by steam having a pressure of 5 pounds by the gauge, the outside temperature being 10° below zero. Let us suppose that the windows are each 6 ft. × 3 ft. and that the exposed walls are built of good ordinary brick, lathed and plastered inside.

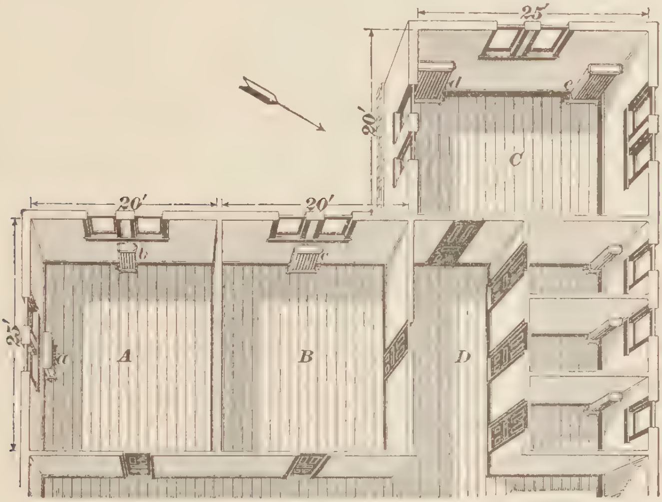


FIG. 48.

Let S = number of square feet of radiating surface required to counteract the cooling effect of the glass and its equivalent in *exposed* wall surface;

t = difference in degrees F. between the desired temperature of the room and that of the external air;

t_1 = difference in degrees F. between the temperature of the heating surface and that of the air in the room;

s = number of square feet of glass and its equivalent in exposed wall surface.

Then, expressing rule 3, Art. **94**, as a formula, we get

$$S = \frac{t}{t_1} s.$$

When lathed and plastered brick walls are used, as in the figure, it is safe to estimate that about 10 square feet of wall surface will be equivalent in cooling power to 1 square foot of glass; consequently, in this case

$$\frac{\text{wall surface}}{10} = \text{equivalent glass surface.}$$

Let us commence with the room A; the amount of glass surface here is $6 \times 3 \times 4 = 72$ square feet. To this must be added the exposed wall surface reduced to a glass equivalent; thus,

$$\frac{10\,(25 + 20) - 72}{10} = 37.8 \text{ square feet.}$$

Since we assume that the inner walls, floors, and ceilings are not cooling surfaces, the only cooling surfaces we have to calculate against in the case of A is 72 square feet + 37.8 square feet = 109.8 square feet = s.

96. The temperature of steam at 5 pounds gauge pressure is 227°, and the difference between 70° above zero and 10° below zero is 70° + 10°; therefore, substituting in the formula, we have

$$S = \frac{70 + 10}{227 - 70} \times 109.8 = 56 \text{ square feet, nearly.}$$

This, however, only counteracts the cooling effect of the walls and windows, and to make reasonable allowance for air leakage, we will add 25 per cent. of the above amount, or 14 square feet, which gives us 56 + 14 = 70 square feet of direct radiating surface.

Now, suppose that we allow 20 per cent of the direct radiating surface (70 square feet in this case) for a moderate exposure to winds; the amount of heating surface, that is, the size of the radiator that we would place in A, will then be 70 + 14, or 84 square feet.

For convenience, we may divide this into two radiators, a having an area of 56 square feet and b an area of 28 square feet. This will so divide the radiator surface that one-third, or 28 square feet, may be used for duty during mild

weather; two-thirds, or 56 square feet, for moderate cold weather, and the whole, or 84 square feet, for use during severe weather.

In like manner and under the same conditions, we find that the sizes of the radiators *c*, *d*, and *e* should be, respectively, 40, 82, and 42 square feet.

As the coldest winds blow in the direction of the arrow, we place the 82-square-feet radiator in the left-hand exposed corner of the room *C*. A better distribution of the radiator surface in this room would be to make *d* 42 square feet only and place a radiator having 40 square feet between the windows towards which the arrow points; this will give a more uniform temperature to the room.

97. The reader will observe that *A*, *B*, and *C*, which are three rooms having the same shape and cubical contents, respectively, require 84 square feet, 40 square feet, and 124 square feet of heating surface, in order to maintain a temperature of 70° F. in each while the outer atmosphere is 10° below zero, and he will observe how imperfect must be the rule-of-thumb method of proportioning radiators to the cubical contents of the several rooms. Baldwin's rule should always be used where possible, in preference to the method described in Art. **92.**

OPERATING A HEATING PLANT.

98. A steam-heating plant really requires but little attention. All the engineer or janitor has to do with an ordinary system while it is in operation is to insure a steam pressure sufficient to produce good heating results. In ordinary cases this pressure is from 1 to 5 pounds by the gauge. He should inspect the system occasionally, at least once a month. In such an inspection he will invariably find that some radiator valves leak through the stuffing-box. These can easily be repacked without affecting the operation of the heating system, for by closing the radiator valve the steam pressure is taken off the stuffingbox. He

may find that some air vents "spit water" or blow steam when they really should be closed, because the radiators on which they are screwed are hot to the extreme end loop. These defective air vents should be immediately repaired or adjusted, as each case may require. If the inner parts are broken or irreparably defective, the engineer should replace the old vent with a new one; they are too cheap to waste much time on in repairs. The engineer should keep a stock of air vents on hand.

If when steam is on and the radiator valve open, the radiator does not heat, it is evident that the air valve is choked or otherwise closed so that it will not let out the air.

99. When a radiator valve is closed and a hissing or hammering noise is heard in the radiator, it is evident that the valve is not tight. A new disk, preferably of the Jenkins variety, should be put on. This requires shutting off steam from the riser line to which such a radiator is connected. If the radiator is connected on the two-pipe system, the return riser must also be shut off, otherwise the steam pressure may back up the water of condensation into the radiator through the returns and flood the building; or steam in the return riser will blow through the radiator and escape at the radiator valve when the bonnet is unscrewed.

100. Before replacing a valve stem and disk, it is proper to examine the valve seat carefully to see if it has a smooth, true face. If a groove has been ground out or the valve face is rough, it is advisable to grind it or to face it smooth and true with a reseating tool.

101. Before the steam is turned on a heating system in the autumn, all necessary repairs should be made and everything should be clean and ready for firing up at a moment's notice or for turning on steam from a power boiler or engine exhaust. The heating boilers, if any, should have been blown out and cleaned the preceding spring, when the system was put out of service for the summer. The return mains should all be drained clear at the same time. All valves should be examined and repaired, if

necessary, during the summer. This will prevent considerable trouble during the winter.

102. As floors and walls are liable to "settle," it is often necessary to readjust the steam-pipe hangers so that the grades of the pipes may be adjusted to prevent water hammer. This, also, should be attended to during the summer. Indeed, nearly all the attention that a heating system of the ordinary character requires is during the summer, when the engineer in charge of it usually has some spare time. And if a heating system receives proper attention during the summer, it should run all winter without repairs.

STEAM TURBINES

CONSTRUCTION AND OPERATION

GENERAL INFORMATION

INTRODUCTION

1. The translation of the energy in steam into rotary motion by means of mechanical appliances has been attempted at various times and places for the past two thousand years. The earliest form of steam engine was naturally the one that required the least mechanical skill and precision of workmanship, and took the form of a globe mounted on trunnions, with two orifices for the discharge of steam, situated at diametrically opposite points of a circle on the sphere drawn midway between the points of suspension. These orifices were so fitted with bent tubing that they discharged the steam in a direction opposite to the direction of rotation of the sphere, and tangential to the circle in which they moved.

The rotation of the sphere on its trunnions is caused by the reaction of the jet of steam as it escapes into the surrounding atmosphere, and hence it is a **reaction motor.** Its principle of operation may be explained as follows: The pressure at every point of the inner surface of the bent discharge tube is balanced by the pressure on a point

opposite; hence, if there were no opening for the escape of steam, there would be no tendency to rotate. But, by making an opening in the end of the bent tube the pressure on the surface opposite becomes unbalanced and rotation begins. From this it follows that the force tending to rotate the sphere is proportional to the area of the opening, the steam pressure remaining constant. An engine built in England about 1883 on the model of this ancient motor showed a water consumption of about 40 pounds per brake horsepower.

The next appearance of a steam motor in history was in 1629, when Branca proposed a type of motor in which the steam upon issuing from a nozzle impinged upon the blades, or vanes, of a paddle wheel. This type may be regarded as the forerunner of the **impact turbine,** of which the De Laval turbine is the present representative. The Parsons turbine, differing from the De Laval machine mainly in the method of securing a high ratio of expansion of the steam, dates from 1884. It is claimed by the inventor that it is a combination of the reaction and impact types. The Curtis turbine was placed on the market in 1903 by the General Electric Company, Schenectady, New York. The De Laval, Parsons, and Curtis turbines are the only types that have at present attained any degree of commercial success for general work in the United States of America.

GENERAL ADVANTAGES

2. The advantages claimed for the De Laval steam turbine are no leakage from wear, small friction loss, high efficiency with variable loads, no moving parts under pressure, close speed regulation, simplicity of construction, perfect balance, small foundations, small space occupied, ease of erection, automatic oiling, no danger from water, and long life.

The advantages over reciprocating engines claimed for the Westinghouse-Parsons turbine are increased speed,

greater economy of steam, reduced weight, reduced space occupied by machinery, reduced cost of attendance, reduced repair bills, and reduced vibration. The same advantages are claimed for the Curtis turbine, comparing it with reciprocating engines.

DE LAVAL TURBINE

WHEEL AND NOZZLES

3. The steam turbine as produced by De Laval was first made a success in 1883. Its first application was in connection with dairies in the cream-separator machines, where its high speed, simplicity of construction, and compactness made it an almost ideal motor for this class of work, and hence it was extensively adopted for it.

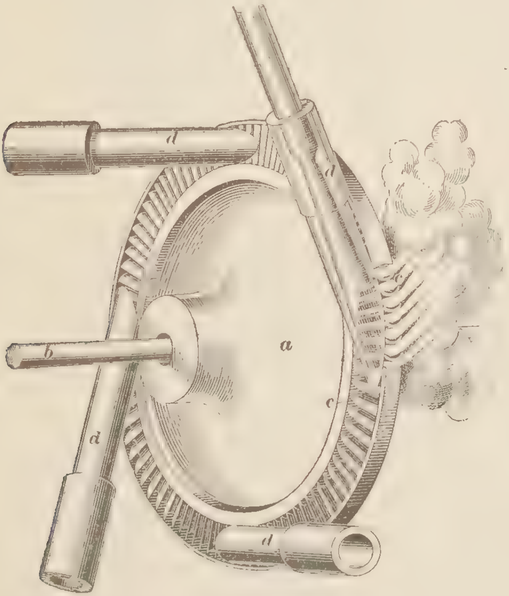


FIG. 1

In the form in which it was first placed on the market, it did not utilize the expansive capabilities of the steam in

producing a high velocity of discharge, and, consequently, the turbine was uneconomical in the use of steam. Means for utilizing the steam expansively were applied later, however, and made the turbine quite an economical machine.

4. The De Laval turbine consists essentially of a wheel *a*, Fig. 1, suitably mounted on a shaft *b*, free to revolve in bearings. The wheel carries at its periphery a large number of radial vanes, or blades, *c*, *c* of a curved cross-section. In order to show these vanes clearly, a piece of the rim has been broken away. Steam is led to the wheel by means of stationary nozzles, as *d*, *d*, varying in number from 1 to 12, according to the size of the turbine. The nozzles are so placed that the steam issuing from them at a high velocity impinges on the blades, and thus rotates the wheel, which is enclosed in a suitable casing. Proper means are provided for regulating the quantity of steam discharged by the nozzles, and thus the horsepower developed is varied.

GENERAL DESCRIPTION

5. The general arrangement of the component parts of the De Laval steam turbine is shown in the sectional plan view given in Fig. 2. The turbine wheel *a* is mounted on the flexible shaft *b* running in the three bearings *c*, *d*, *d* and the so-called flexible bearing *c'*. The bearings *d*, *d* are rigid; the bearing *c*, however, is fitted in such a manner that it can accommodate itself to any bending of the shaft. The flexible bearing *c'* is really not a bearing at all, since it does not support the shaft, but merely closes the opening where the shaft passes out of the casing. In reality it is a stuffingbox so mounted as to accommodate itself to any bending of the shaft, and preventing the entrance of air to the casing *e* when running condensing, and the escape of the steam when running non-condensing. The turbine wheel runs within the

casing *e* that carries the nozzles that owing to the view taken cannot be shown. The position of the nozzles in regard to the wheel has, however, been clearly illustrated in Fig. 1. The turbine wheel has such a high rotative speed that very little machinery in use can be coupled directly to the shaft *b*; in order to reduce this high rotative speed to the limits

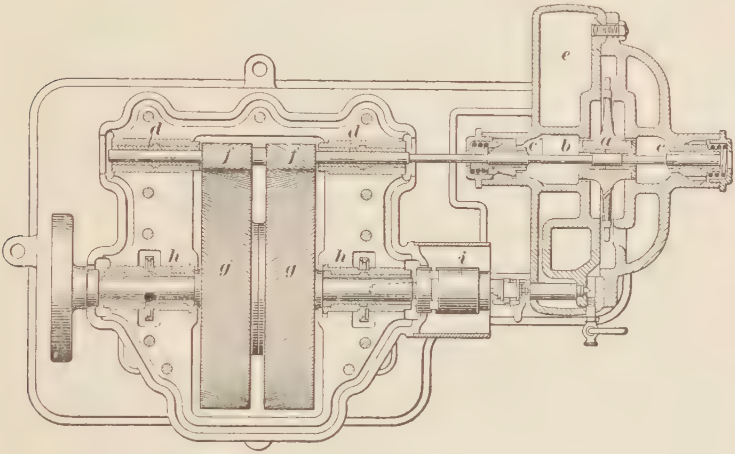


FIG. 2

of usual practice, gearing is resorted to. The shaft *b* is extended as shown and carries the two pinions *f*, *f* meshing with the gear-wheels *g*, *g*, which generally have 10 times as many teeth as the pinions, thus reducing the speed to $\frac{1}{10}$ the speed of the turbine wheel. The gears have helical teeth, and one set of gears has right-handed helical teeth while the other set has left-handed helical teeth. In consequence of this, there is practically no chance for the shaft to move endwise. The gears are enclosed in a closed case partially filled with oil. The machine to be driven by the turbine is connected to the shaft *h*, either by being coupled to it directly, or by being belted to a pulley keyed to the shaft. The shaft *h* carries on one end the centrifugal governor *i* that operates a double-seated throttle valve by means of a bell-crank lever. This lever *l* is clearly shown in Fig. 3, which is an elevation of the same turbine shown in Fig. 2,

and where all visible parts have been lettered the same as in Fig. 2. Steam is admitted to the turbine through a pipe

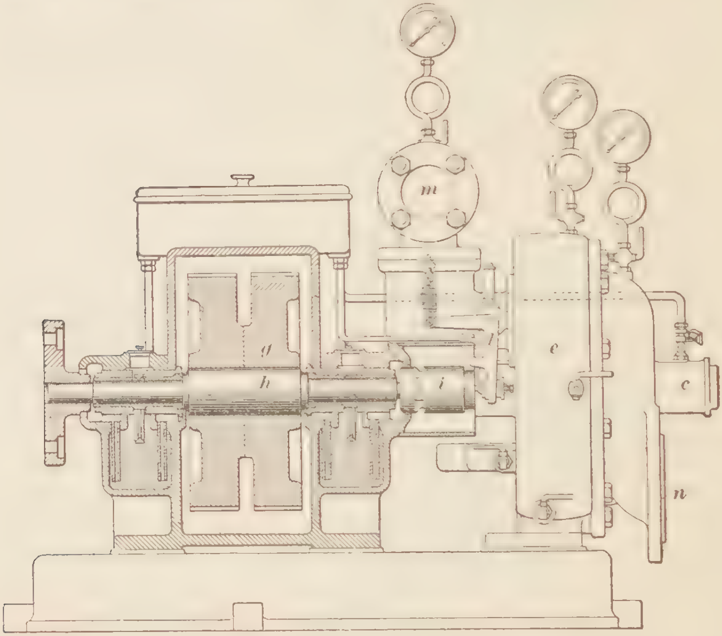


FIG. 3

screwed into the flange *m*; the exhaust pipe leading either to the atmosphere or to a condenser is bolted to the flange *n*.

GOVERNOR AND VACUUM VALVE

6. The construction of the **governor** is shown in Fig. 4. It consists of a frame fastened to the end of the shaft by a taper shank and carrying the weights *a*, *a* hung on knife-edge bearings. These weights fly outwards under the action of the centrifugal force until the resistance of the springs *b*, *b* is equal to the centrifugal force. In moving outwards, the weights force the governor stem *c* to the right, which in turn rotates the bell-crank and causes the governor valve operated by it to assume a position corresponding to the speed of the governor. When the speed falls, the governor

weights move inwards, and the governor valve is opened farther by them, thus admitting more steam. When the speed rises, the centrifugal force increases and the governor weights move farther outwards; this closes the governor valve farther and thus reduces the amount of steam admitted.

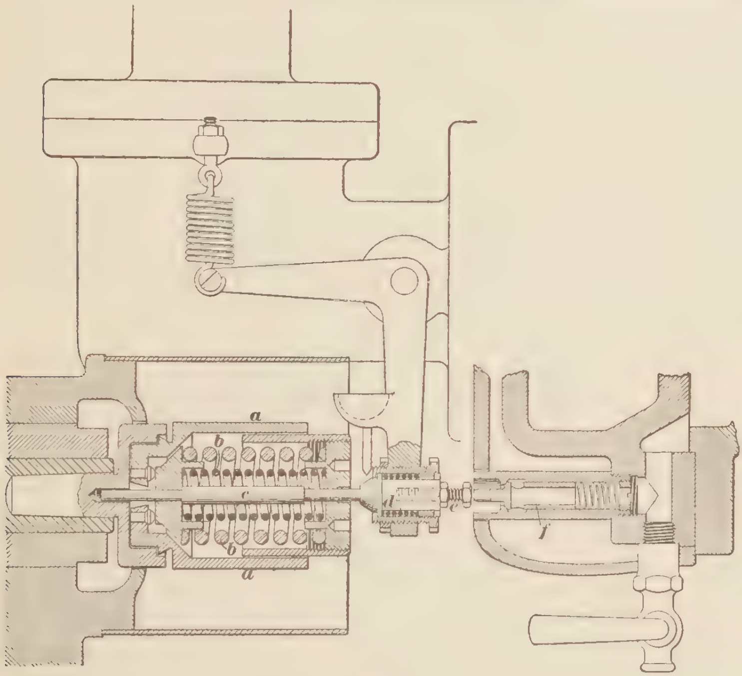


FIG. 4

The speed at which the turbine will run can be varied somewhat by changing the tension of the governor spring, increasing the tension to make the turbine run faster and decreasing it to make the turbine run slower.

7. When the turbine is running condensing, it has been found that the governor valve alone will not give a sufficiently close regulation during a sudden and excessive decrease of load. To assist the governor valve in controlling the speed under these conditions, the **vacuum valve** has been designed. Its function is to admit air to the space in

which the wheel revolves and thus to destroy or impair the vacuum; the resistance of the air then effectually checks the speed of the wheel. The vacuum valve is operated by the governor as follows: When the speed under a sudden decrease of load becomes excessive, the governor first closes the governor valve entirely. The governor weights continue to move outwards after this and force the governor stem *c*, Fig. 4, farther to the right, compressing the spring *d* in doing so. The adjustable stud *e* then strikes the end of the vacuum valve *f* and forces this valve inwards, thus admitting air. When the speed has been sufficiently reduced, the governor weights move inwards and consequently the stud *e* moves away from the vacuum valve, allowing it to close. As the weights continue to move inwards, they open the governor valve again and admit steam to the turbine once more.

PURPOSE OF THE FLEXIBLE SHAFT

8. The vibration of the shaft and wheel at the high speeds is reduced to a minimum by an extremely careful balancing of the revolving parts, and by making the shaft itself slender and hence flexible. It was found long ago that, with rigid shafts running in rigid bearings, the most careful balancing failed to prevent excessive vibration at very high speeds, as the centrifugal force generated by the absence of absolute balance was very large. The discovery was made, however, that by either making the shaft slender and hence flexible, or by making it very rigid and the bearings capable of lateral accommodation, the rotating parts would vibrate until the so-called *critical speed* was reached and that after passing this speed the vibration would gradually cease. The exact reason for this action is at present a matter of speculation; the most commonly accepted hypothesis is that the special construction permits the parts to revolve about their axis of gravity instead of their geometrical axis, the axis of gravity being the line joining the centers of gravity of the different parallel sections at right angles to the shaft into which the revolving parts may be

conceived to be divided. This discovery has been employed in the De Laval turbine, making the shaft small and hence flexible.

DE LAVAL NOZZLE

9. The means by which steam is used expansively in the De Laval turbine is one of the distinguishing characteristics of this type of turbine, and is known as the **De Laval nozzle.** It consists of a tube *a*, Fig. 5, with a contracted opening,

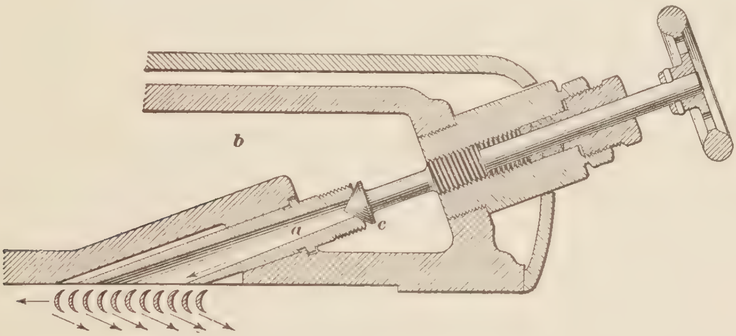


FIG. 5

or *throat*, near the inlet end. The steam passage in the nozzle diverges from the throat to the outlet end. The inlet ends of the nozzles are within the annular passage *b* concentric with the shaft, and to which the live steam is admitted. The valve *c* regulates the amount of steam entering each nozzle, and is also used for cutting one or more nozzles out of service when the turbine is not to be worked under a full load.

The purpose of the expansion nozzle is to greatly increase the velocity with which the steam strikes the blades of the turbine wheel. Since the amount of work a moving body can do in being brought to rest varies as the square of the velocity, it can readily be seen that the work a given weight of steam can do in a turbine is greatly increased by even a small increase in its velocity.

It may appear on first thought that the velocity of steam issuing from an orifice, as a nozzle, can be increased

best by increasing the difference in pressure between that of the steam entering the nozzle and that in the space into which the steam is discharged. In carrying out this idea in practice, however, the fact is encountered that the velocity of steam issuing from an orifice in a thin plate, or from a converging nozzle, into a space of less pressure only continues to increase as the difference in the pressure increases until the pressure in the space of less pressure is approximately $\frac{4}{7}$ of the steam pressure at the inlet side. After this point is reached, the velocity of the steam remains practically constant, no matter how much farther the difference in pressure is increased.

From the foregoing statements it will be seen that there is a limit beyond which it is inadvisable to raise the pressure of the entering steam, since no increase of velocity will result from a further increase, considering an orifice in a thin plate or a converging nozzle.

It has been discovered that by discharging the steam through a nozzle with diverging sides, as the De Laval nozzle illustrated, an increase of velocity at the discharge end beyond the limit imposed by the phenomenon explained above can be obtained, the steam in passing through the nozzle expanding down to a low pressure. The object, then, of the De Laval nozzle is to impart a high velocity to the steam, thus giving a great kinetic energy.

WESTINGHOUSE-PARSONS TURBINE

ACTION OF STEAM

10. The steam motor known to the engineering profession by the name of the Parsons turbine is the invention of an English engineer, Charles Parsons, and was quite highly developed before being introduced into America. The first Parsons turbine was built in 1884 and supplied power for the manufacture of electrical apparatus in Gateshead, England. The Westinghouse Machine Company, of

Pittsburg, Pennsylvania, have obtained the right to manufacture the Parsons turbine in this country, and it is now placed on the market under the name of **Westinghouse-Parsons steam turbine.**

11. In the Westinghouse-Parsons steam turbine the steam is discharged successively upon a number of wheels carrying blades, and placed side by side on the shaft, fixed guide blades being placed between each pair of wheels. This turbine differs radically from the De Laval turbine in the manner in which expansion is secured. In the De Laval turbine the expansion takes place in the nozzle and the steam strikes the wheel at a very low pressure; in the Westinghouse-Parsons turbine expansion takes place as the steam passes from one wheel to the other, and steam at full boiler pressure impinges on the first wheel, the pressure decreasing as the steam passes from wheel to wheel.

The relative arrangement and shape of the fixed guide blades and the blades in the wheels is shown in Fig. 6, where the line *A B* represents the axis of rotation. The steam on entering the turbine casing flows in a general direction parallel to the shaft, entering first the curved guide blades *a* that deflect it against the blades of the first wheel *b*. The impact of the steam causes the wheel to revolve. The steam rebounds from the moving blades to the guide blades *c* that deflect it again against the moving blades of the wheel *d*, whence it passes to another set of guide blades, and so on. It will be understood that all of the turbine wheels are fastened to the same shaft and revolve together. The wheels are caused to rotate both by the impact of the steam delivered against their blades, and the reaction of the steam rebounding from them. Hence, it is seen that the

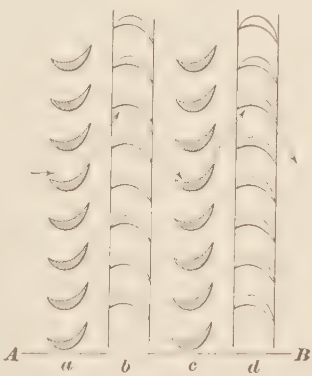


FIG. 6

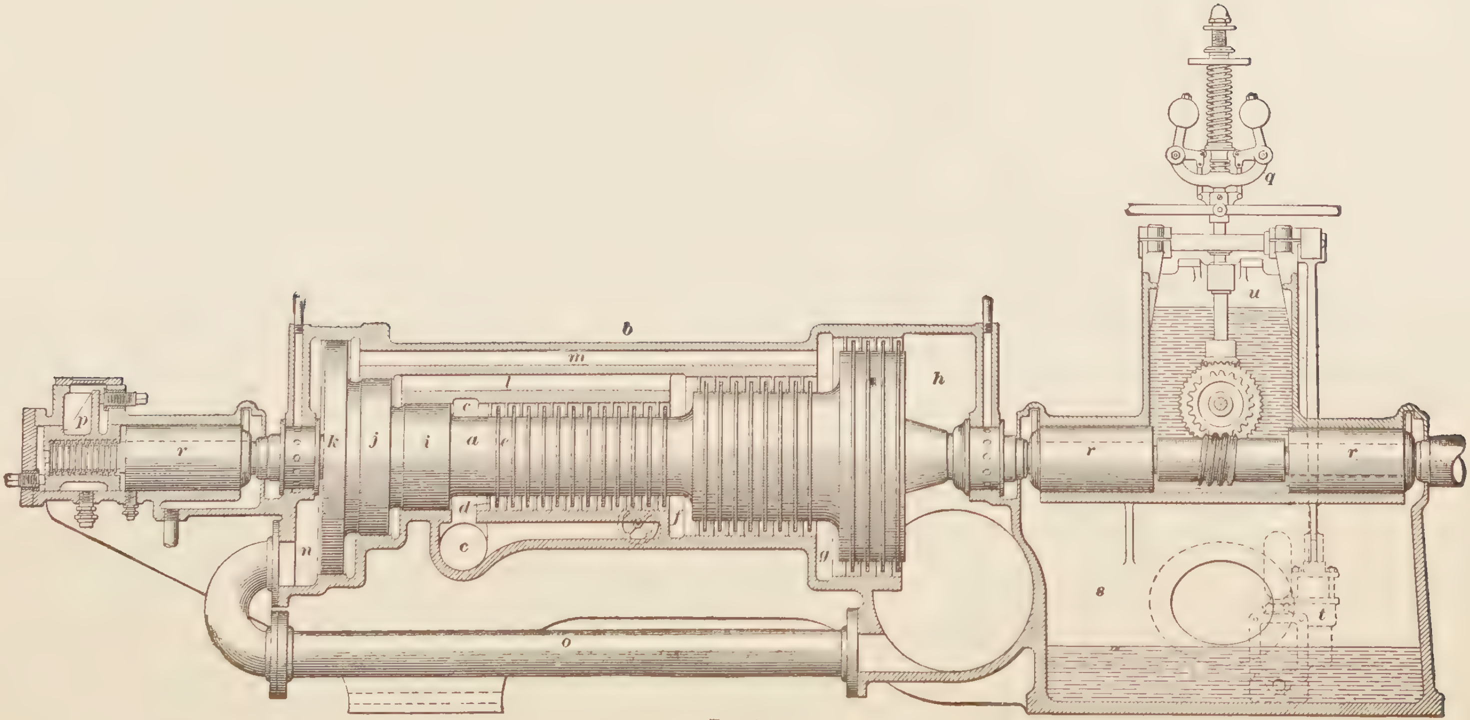


FIG. 7

Westinghouse-Parsons steam turbine is a combination of the reaction and impact types of the turbine.

12. The steam yields the kinetic energy due to its velocity of flow in the following manner: It enters the first stationary set of guide blades at its maximum velocity and is discharged against the moving blades, from which it rebounds at a reduced velocity and enters the space containing the second set of guide blades. This space is larger than the first space containing guide blades, and in consequence the steam expands. In doing so its velocity of departure is increased somewhat above the velocity with which it entered the second space, but not up to the velocity with which it entered the first space containing guide blades. The steam leaves each successive space containing guide blades at a velocity below that with which it departed from the preceding space, until on finally leaving the turbine its velocity is very low. From the foregoing it will be seen that the steam does not part all at once with the kinetic energy it is practicable to abstract, as occurs in the De Laval turbine, but parts with it in successive stages. In the De Laval turbine, in order to get maximum efficiency, the velocity of the wheel must be about 47 per cent. of the velocity of the steam, and as this latter velocity is very high, about 4,000 feet per second, the turbine wheel must have a very high rotative speed and the motor requires to be geared down for most work. In the Westinghouse-Parsons turbine, however, the velocity is reduced gradually, and consequently the peripheral speed, that is, the speed of rotation, of the wheels is comparatively low. This is a decided advantage for many purposes, since it allows the motor to be connected directly to many machines.

GENERAL ARRANGEMENT

13. The general arrangement of the parts of a Westinghouse-Parsons steam turbine is given in the sectional view shown in Fig. 7. The turbine shaft *a*, carrying three sets

of moving blades, rotates in suitable bearings and within the casing *b*. Steam at boiler pressure enters the annular passage *c*, whence it passes to the first set of stationary guide blades *d*, which direct it against the blades of the wheel *e*. After passing the first set of wheels, the steam, which now has lost considerable of its velocity, flows into the annular chamber *f* and impinges on the second set of wheels, there parting with more of its kinetic energy. The steam passes then into the annular chamber *g* and impinges on the third set of wheels, finally passing at a very low velocity into the chamber *h*, and thence either to the atmosphere or to a condenser. In order to counteract the end thrust of the steam against the moving blades, the shaft is fitted with balance pistons *i*, *j*, and *k*. The piston *i* has an area equal to that of the moving blades of the first set of wheels, and as the steam pressure acts against this piston in a direction opposite to that in which it acts against the blades, the end thrust is balanced. Likewise, the end thrust against the second and third set of blades is balanced by the pistons *j* and *k*, which are subjected to the steam pressure existing in the chambers *f* and *g*, since the chambers in which these pistons revolve are connected by the passages *l* and *m* to the chambers *f* and *g*. In order that the pressures on the outer side of the balance piston *k* and the outer side of the largest set of blades may be equal, the chambers *h* and *n* are connected by a pipe *o*. An adjustable bearing *p* similar to a thrust block confines the turbine shaft longitudinally, and at the same time resists any end thrust that may not be balanced by the balance pistons. A governor *q* serves to regulate the speed of the engine. Live steam can be admitted to the chamber *f* by a by-pass valve for the purpose of increasing the power of the turbine. This, however, is accompanied by a reduction in the economy. Flexible bearings *r*, *r*, *r* permit the shaft and wheels to revolve about their axis of gravity. All bearings are lubricated by oil under pressure, which flows back by gravity to the reservoir *s*, whence the pump *t* forces it back into the supply reservoir *u*, from where it passes once more to all bearings.

FLEXIBLE BEARINGS

14. The means adopted for preventing vibration are an extremely careful balancing of the revolving parts combined with a construction permitting a lateral accommodation of the bearings. In the Westinghouse-Parsons steam turbine the shaft is made just as rigid as possible.

The construction of the bearings is as follows: The gun-metal sleeve forming the bearing proper is prevented from rotating by means of a dowel. This sleeve is surrounded by three loosely fitting tubes. The space between the tubes themselves and the sleeve is filled with oil, which is supplied under pressure. Owing to the oil being a yielding medium, the sleeve can move laterally to accommodate itself to a displacement of the geometrical axis of the shaft.

GOVERNOR

15. The governor, as an inspection of Fig. 7 will show, is a spring-loaded fly-ball governor. By adjusting the tension of the spring loading it, the speed of the turbine can be varied within small limits. The governor valve controlling the admission of the steam to the turbine is not attached directly to the governor, but is operated by steam admitted to its power cylinder and exhausted therefrom by a pilot valve controlled by the governor.

The governing mechanism is shown in Fig. 8. The steam-admission or governor valve is attached to a stem *a* carrying a piston *b* working in a cylinder *c*. A spring *d* placed on top of the piston *b* tends to return it to, and keep it in, its lowest position, where the admission valve is fully closed. In operation, steam at boiler pressure leaks past the stem *a* and raises *b*, thereby opening the governor valve. Steam is exhausted from the under side of the piston by means of the pilot valve *e*, thereby lowering the pressure below *b* and thus permitting the spring *d* to close the governor valve. The pilot valve is given a to-and-fro motion while the

turbine is running by means of an eccentric on the shaft driving the governor, the eccentric rod *f* being attached to the lever *g*, which in turn is connected to the lever *h* by the link *i*. The lever *h* in turn is connected to a crank *j* by a link *k*, the crank *j* being connected to the

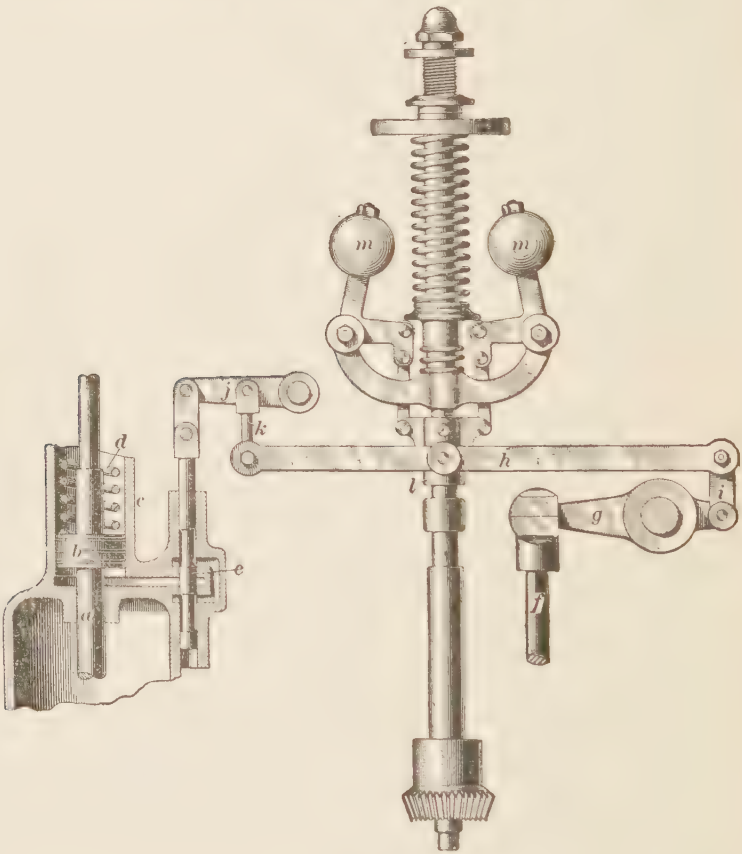


FIG. 8

pilot valve *e*. The fulcrum of the lever *h* is placed on the governor collar *l*, and consequently under any change of speed, since the governor balls *m*, *m* move in or out and raise or depress the collar, the height of the fulcrum changes.

16. The action of the governor can best be studied by considering first of all the action of the admission valve while the turbine is running at a constant speed. With each revolution of the shaft when it is driving the governor, the pilot valve is opened and the steam is exhausted from the under side of the piston shown at *b*, which moves downward and causes the steam-admission valve to close, thus completely closing the steam inlet. After a certain interval the pilot valve closes the exhaust port from the under side of the piston, and the accumulation of pressure opens the admission valve again, admitting steam once more to the turbine. This alternate closing and opening of the admission valve occurs about 150 times per minute. It is thus seen that the steam is admitted in puffs, as it were.

Reflection will show that the volume of steam admitted at each opening of the governor valve varies directly as the length of time the valve remains open. The object of the governor is to regulate this length of time, which is accomplished by causing the pilot valve to make its strokes in a higher or lower position, according to which way the speed varies, thus changing the length of time the port leading below the piston *b* remains open. Let us suppose the speed of the turbine increases. Then, the governor balls *m*, *m* fly outwards, and in doing so pull up the governor collar *l*. As a result of this, the pilot valve is also lifted and now makes its up-and-down strokes in a higher position. In consequence of this, the port leading below the piston *b* remains open for a greater length of time than before, with the result that the spring *d* is permitted to hold the steam-admission valve closed longer, or in other words, shortens the time during which steam is admitted to the turbine. The result of this decrease in the volume of steam admitted to the turbine is a reduction of its speed down to the normal speed. When the speed drops below that of the normal speed, the pilot valve drops to a lower position, thus reducing the time during which steam is exhausted from below the piston *b*, and consequently increasing

the time the steam-admission valve remains open. The result is that more steam is admitted at each opening of the valve, which continues until the speed has increased to the normal speed.

The object of making the admission valve act intermittently, as described, is to admit the steam to the turbine at full boiler pressure irrespective of any variation in load. With a full load the puffs of steam admitted will be almost continuous.

CURTIS TURBINE

ARRANGEMENT OF BLADES AND NOZZLES

17. The Curtis steam turbine, which is manufactured by the General Electric Company, of Schenectady, New York, in some respects combines the principles which are employed in the operation of the De Laval and Parsons turbines, using the expansion nozzles of the first make

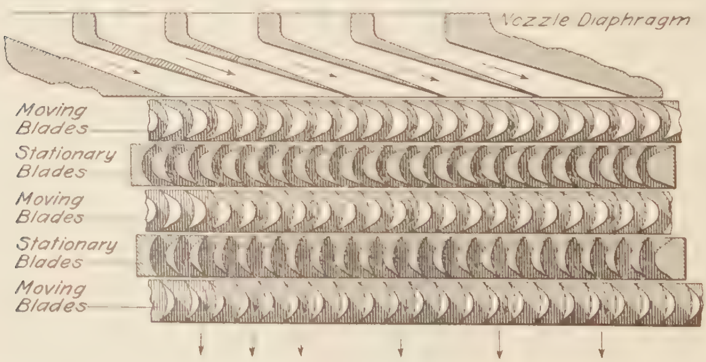


Fig. 9

and the alternate rows of stationary and moving blades acted upon by the steam that are employed in the second make of steam turbine mentioned. The Curtis turbine, as manufactured at present, is vertical; that is, the shaft is vertical and the wheels carrying the moving blades revolve in horizontal planes.

18. A diagrammatic view showing the arrangement of the expansion nozzles, stationary blades, and moving blades is given in Fig. 9, the direction of flow of the steam being indicated by the arrows. The steam is first expanded to a low pressure in the expansion nozzles, having its velocity of flow increased thereby; the kinetic energy of the steam is then abstracted in successive stages by the rows of moving blades. A comparatively low speed of rotation is secured by making the wheels carrying the moving blades large in diameter; this allows the speed at the circumference to be high enough to suit the velocity of flow of the steam.

ARRANGEMENT OF TURBINE

19. A sectional view of one form of the Curtis turbine is given in Fig. 10, the particular machine shown being designed to normally develop 6,700 actual horsepower. The vertical shaft *a* is supported sidewise by bearings *b*, *b* and in a vertical direction by a step bearing *c*; the shaft carries a number of horizontal wheels, as *d*, *d*, two in this case and three or four in others. These wheels at their circumference carry steel rings in which the blades are formed by cutting from the solid metal; stationary guide blades, as *e*, *e*, are placed between each two rings of moving blades, as *f*, *f*. The stationary blade rings are supported by the casing *g*. Governing is affected by valves, as *h*, placed in the passage leading to each expansion nozzle, these valves being operated by a governor not shown. The exhaust steam in the design shown passes from the space *i* to the condenser; in some designs the condenser is placed directly in the base, that is, within the space *i*. A Curtis turbine having two wheels, as *d*, *d*, is called a two-stage turbine; if it has three wheels, it is spoken of as a three-stage turbine, and so on. Oil under pressure is forced by a pump into the step bearing, so that while running the shaft is supported on a film of oil. None of the oil used for lubrication mingles with the steam, which makes

the condensed steam at once suitable for boiler feeding. All stationary blades do not extend around the circumference of the wheels *d*, *d*; the first row extends slightly beyond the nozzles; which are placed on one side of the machine; each succeeding row of stationary blades extends somewhat farther around the circumference and the final row or rows extend all around. As at present constructed,

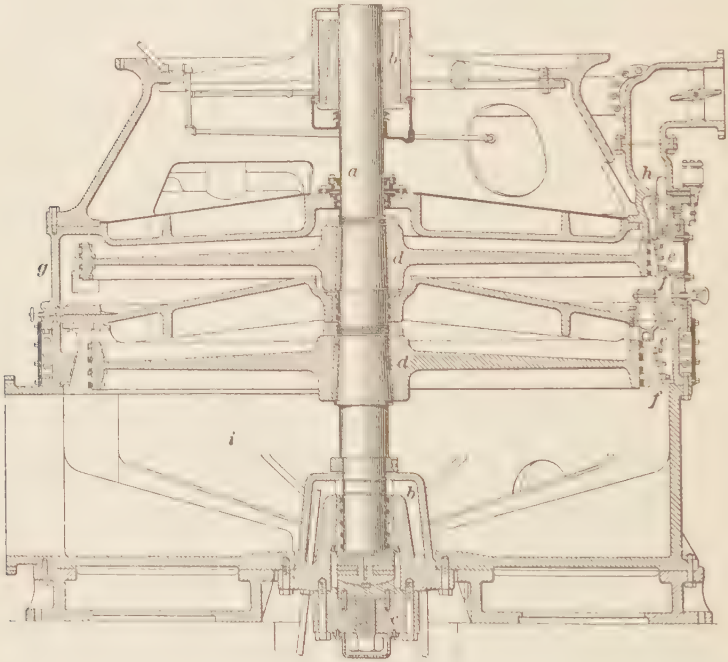


FIG. 10

the governor itself operates electromagnets, which in turn shut off successive nozzles, by closing their valves whenever the speed exceeds the desired limit. One of the nozzles has its controlling valve so arranged that the flow of steam through it can be throttled to any extent permitted by the construction; the other controlling valves are either opened or closed entirely by the governing mechanism.

GENERAL COMPARISONS

ADVANTAGES AND DISADVANTAGES

20. The fundamental difference in the operation of the common reciprocating-piston steam engine and of the steam turbine is that, while in the former the steam does work by reason of its pressure overcoming resistance, in the latter the steam does work by yielding its kinetic energy.

21. One of the greatest losses of heat in a reciprocating engine is due to the steam entering passages the walls of which have been cooled by contact with steam of much lower temperature. The weight of steam that is condensed and passed through a reciprocating engine without doing useful work, according to Dr. R. H. Thurston, amounts to about 25 per cent. of the total steam consumption of the engine. In the turbine this loss is entirely eliminated. The walls of the steam passages in the turbine soon attain a temperature equal to the temperature of the passing steam, and as the temperature of the steam at any given point does not vary, it follows that there is no transfer of heat between the steam and surrounding metal. This causes a practically ideal expansion of the steam.

22. A loss of energy to which the turbine is subject and that has no counterpart in the reciprocating engine may be caused by moisture in the steam; thus, a drop of water falls on the wheel and is given a velocity equal to that of the blades. As soon as it attains this velocity, centrifugal force causes it to fly off against the casing, where its kinetic energy is dissipated; falling back on the wheel it goes through the same cycle of operations again and continues to abstract energy from the revolving blades. Dr. R. H. Thurston, experimenting with a 10-inch De Laval turbine running at 20,000 revolutions

per minute, estimates the loss from this source to be 1 horsepower for every 275 drops of water, each having a diameter of $\frac{1}{10}$ inch.

Another loss due to moisture in the steam is the retardation of the wheel caused by a thread-like stream of water between the revolving disk and the sides of the casing. The same author, experimenting with the same turbine, estimates the loss due to a thread of water $\frac{1}{1000}$ inch in width between the casing and the wheel to be $1\frac{1}{2}$ horsepower per hour.

23. The obvious remedy for loss due to moisture is the use of highly superheated steam, which is possible, since, unlike the reciprocating engine, the turbine has no rubbing surfaces on which lubrication is made difficult by steam of a high temperature. The trouble due to charred and burnt packing in stuffingboxes is also obviated, as there is no packing around the turbine to burn. With the reciprocating engine the limit to which superheating may be carried is set by the engine, while with the turbine the limit is set by the superheater. Experiments with a De Laval turbine conducted at Sibley College, Cornell University, show a gain of 1 per cent. in efficiency for every 30° of superheat. Other experiments with other turbines show a gain of 20 per cent. in economy with 60° superheat.

24. The efficiency of steam turbines measured by the water consumption per horsepower equals and in some cases excels that of the best types of modern reciprocating engines. The use of oil is much less than with the more common type of engine, as there are comparatively few bearings to oil, and no cylinder oil is required, owing to the absence of internal rubbing surfaces. This latter fact is quite a decided advantage when exhaust steam is condensed and returned to the boiler, since the water will be entirely free from oil.

Turbines are worked with a very high ratio of expansion, which is frequently as high as 1 : 150.

HORSEPOWER OF STEAM TURBINES

25. The horsepower developed by a steam turbine cannot be readily computed from an indicator diagram, as is done with reciprocating engines; in practice it is measured by means of some form of a dynamometer, as a Prony brake, for instance. For this reason, whenever the horsepower of a steam turbine is mentioned, the brake, or actual, horsepower is meant. This fact must be clearly borne in mind when making a comparison of the horsepowers of a reciprocating engine and a steam turbine, since in the reciprocating engine the indicated horsepower is always given, unless distinctly stated otherwise. The indicated horsepower of such an engine is always much more, probably by 20 per cent. on an average, than the actual delivered horsepower, the difference being required to overcome frictional resistances within the engine.

A SERIES

OF

QUESTIONS AND EXAMPLES

RELATING TO THE SUBJECTS
TREATED OF IN THIS VOLUME.

It will be noticed that the Examination Questions that follow have been divided into sections, which have been given the same numbers as the Instruction Papers to which they refer. No attempt should be made to answer any of the questions or to solve any of the examples until that portion of the text having the same section number as the section in which the questions or examples occur has been carefully studied.

DYNAMOS AND MOTORS.

EXAMINATION QUESTIONS.

(1) Suppose that a ring-core armature of a bipolar dynamo is wound with 200 complete turns of wire that are properly connected to the segments of a commutator for generating a continuous current, and that there are 6,250,000 lines of force passing through the armature from the poles of the field magnets. If the strength of the field remains constant and the armature is rotated at a uniform speed of 1,200 revolutions per minute, what is the total electromotive force in volts generated in the armature?

Ans. 250 volts.

(2) If the resistance of the field coils in a shunt-wound dynamo is 440 ohms, and the difference of potential between the brushes when the external circuit is open is 220 volts, what is the strength of current in the field coils?

Ans. .5 ampere.

(3) What is the distinction between an alternating current and a continuous current?

(4) Fig. I shows a cross-sectional view of a uniform magnetic field taken at right angles to the direction of the lines of force; that is, the dots represent the ends of the lines of force, their direction being downwards, piercing the paper. *C* represents a closed coil of some conducting material, such as copper, that is placed in the magnetic field with its plane

at right angles to the direction of the lines of force. If the closed coil is suddenly moved from its original position to another position in the field, as to C', as shown by the dotted coil, without changing the relative position of its plane with the direction of the lines of force, state whether or not a momentary current will circulate around the coil when the movement is made, and give the reason.

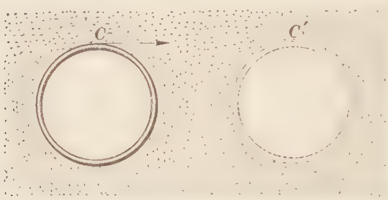


FIG. I.

(5) The output from a certain dynamo is 17,500 watts, and its efficiency at this output is 87.5 per cent. If 2.6 per cent. of the input is used to excite the field magnets, state the field loss in watts. Ans. 520 watts.

(6) The resistance of the shunt field coils of a constant-potential dynamo is 55 ohms and the difference of potential between the brushes when the armature is revolving at normal speed is 110 volts. How many watts are required to excite the field magnets? Ans. 220 watts.

(7) What is a commutator and for what is it used?

(8) The output of a dynamo is 65,000 watts and its efficiency at this output is 90.5 per cent.; determine the input to the armature and express the same in horsepower.

Ans. 96.28 horsepower.

(9) Fig. II shows the connections of a shunt-wound dynamo and the direction in which the field coils are wound. If the current flows in the direction indicated by the arrowheads, which of the two pole pieces, P or P', is the north pole? Suppose that the winding of the right-hand coil were reversed, which pole piece would then be the north pole?

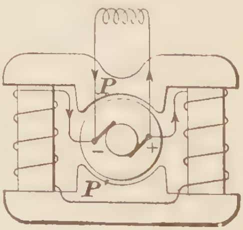


FIG. II.

(10) The input to a dynamo is 10 horsepower and its output is 6,341 watts. What is its efficiency at this load?

Ans. 85 per cent.

(11) Fig. III represents a cross-sectional view of a uniform magnetic field. The dots represent an end view of the lines of force, their direction being downwards, piercing the paper; or, in other words, the observer is looking along the lines of force toward the face of a south pole; *c* represents a moving conductor placed in the magnetic field with its

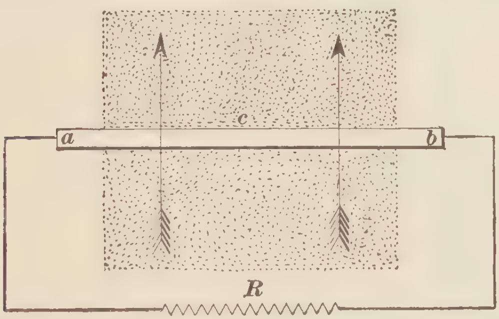


Fig. III.

length at right angles to the direction of the lines of force; its two ends are connected to an external circuit consisting of the resistance *R*. If the conductor is moving upwards across the magnetic field in the direction shown by the arrows, in which direction will the current tend to flow in the circuit?

(12) A dynamo shows an efficiency of 85 per cent. when its output is 11,900 watts, and 1.8 per cent. of the input is lost in the core by eddy currents and hysteresis. What is the core loss in watts? Ans. 252 watts.

(13) (*a*) What is meant by the *counter torque* of a dynamo? (*b*) What causes it?

(14) A dynamo generates 125 volts at a normal load of 120 amperes; if the resistance of the armature from brush to

brush is .040 ohm, what is the armature loss in watts due to resistance? Ans. 576 watts.

(15) In a compound-wound dynamo the resistance of the shunt field coils is 550 ohms and the resistance of the series field coils through which all the current to the external circuit flows is .04 ohm. The dynamo generates 550 volts between its brushes when the output is 40 amperes. Determine the total number of watts lost in the shunt and series field coils combined at this output. Ans. 614 watts.

(16) What causes the neutral points in a dynamo to shift when a current is flowing in the armature conductors?

(17) The separate losses at full load in a particular dynamo are as follows:

Loss in mechanical friction = 356 watts.
Loss in eddy currents and hysteresis = 178 watts.
Loss in field coils = 263 watts.
Loss in armature ($C^2 r$) = 423 watts.
All other losses = 50 watts.

If the output of the dynamo at full load is 15,000 watts, determine its percentage efficiency. Ans. 92.1942 per cent.

(18) In example 17, what percentage of the input is lost (*a*) in mechanical friction? (*b*) in eddy currents and hysteresis? (*c*) in the field coils? (*d*) in the armature wires? (*e*) What is the total percentage of loss in the dynamo?

Ans.
(*a*) 2.1881 per cent. loss.
(*b*) 1.094 per cent. loss.
(*c*) 1.6165 per cent. loss.
(*d*) 2.5999 per cent. loss.
(*e*) 7.8058 per cent. total loss.

(19) If a certain dynamo generates 440 volts when driven at a speed of 1,200 revolutions per minute, what electromotive force will it generate when driven at 1,400 revolutions per minute, all other conditions in regard to strength of field, armature reactions, and number of armature conductors remaining unchanged? Ans. 513⅓ volts.

(20) What advantage have carbon brushes over copper brushes?

(21) Fig. IV represents a cross-sectional view of a uniform magnetic field. The dots represent an end view of the lines of force, their direction being downwards, piercing the paper; or, in other words, the observer is looking along the lines of force towards the face of a south pole. The ring C is

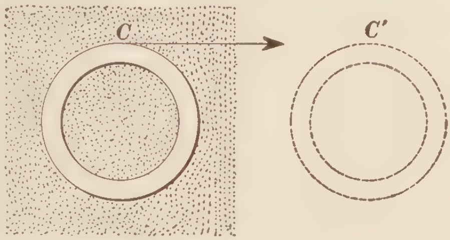


FIG. IV.

a closed coil of some conducting material, as copper, and is placed in the magnetic field with its plane at right angles to the direction of the lines of force. Imagine the coil to be suddenly jerked from its position C to one outside the magnetic field, as, for instance, to C', assuming, of course, that its plane is kept always at right angles to the direction of the lines of force. Will a momentary current be produced in the closed coil, and if so, in which direction will it circulate around the ring?

(22) What is a compound-wound dynamo, and why are dynamos compound-wound?

(23) If a conductor cuts eight million lines of force in one-quarter of a second, what is the *rate of cutting* per second?

(24) State why a solid piece of iron will not answer for a revolving armature core.

(25) In a particular dynamo, if an electromotive force of 200 volts is generated when there are 750,000 lines of force passing through the armature, what electromotive force would be generated if the strength of the field were increased so that 1,250,000 lines of force passed through the armature, assuming that all other conditions as to speed,

number of conductors, armature reactions, etc., remain unchanged? Ans. $333\frac{1}{3}$ volts.

(26) To what are the following losses in a dynamo due: (*a*) core loss? (*b*) armature loss? (*c*) field loss?

(27) In Fig. V, the observer is looking at the face of a north magnetic pole N and a straight conductor C is placed in a vertical position in front of the pole with its length at right angles to the direction of the lines of force as they pass from the pole. If the two ends of the conductor are connected to the terminals of the battery B, and a current flows through the circuit thus formed in the direction indicated by the arrowheads, toward which side, *a* or *b*, of the pole face will the conductor tend to move?

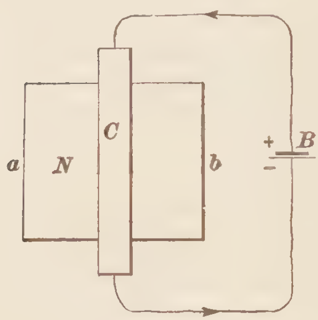


FIG. V.

(28) In a shunt-wound dynamo, if the resistance of the field coil is 650 ohms and the difference of potential between the brushes remains constant at 525 volts when the armature is rotated at a constant speed, what is the strength of current in the field coil under these conditions?

Ans. .8076 ampere.

(29) A compound-wound dynamo generates 115 volts between its terminals when no current is flowing into the external circuit. At full load, however, the difference of potential between its terminals is 124.2 volts. What percentage of over-compounding do these figures represent?

Ans. 8 per cent.

(30) What becomes of the heat generated in a dynamo armature?

(31) State the differences between separately excited, shunt-wound, and series-wound dynamos.

(32) The core losses in a particular generator amount to 800 watts and the input to the generator is 64 horsepower at full load. Determine the percentage of loss in the core at this input. Ans. 1.6756 per cent.

(33) Why must the brushes of the dynamo be shifted ahead of the neutral point when operating under load?

(34) What is the difference between a consequent pole and a salient pole?

OPERATION OF DYNAMOS AND MOTORS.

EXAMINATION QUESTIONS.

(1) Why should the operation of emery wheels, grinders, and speed lathes and the handling of coal not be allowed in the same room with dynamos and engines?

(2) (*a*) On what machines are copper brushes generally used? (*b*) How are copper brushes generally set?

(3) How are (*a*) copper and (*b*) carbon brushes shaped to fit the commutator?

(4) What does the odor of hot oil around a machine usually indicate?

(5) State three possible causes for the refusal of a direct-current shunt motor to start after the main switch has been closed and the starting device properly operated.

(6) To what may the sparking at the brushes of a dynamo be due? Give at least four causes of sparking.

(7) What test may be used to locate defects in an armature?

(8) How would you test the field coils of a dynamo to determine whether any of them were open-circuited or not?

(9) Why should neither ordinary oil, in any considerable quantity, nor emery cloth be used on commutators or brushes ?

(10) Why are carbon brushes used on high-voltage dynamos, especially when they are subject to sudden and violent changes in the load that cannot be met by shifting the brushes ?

(11) How are (*a*) high and (*b*) low bars in commutators remedied ?

(12) What is the result of continually overloading a dynamo ?

(13) How does a shunt motor act when the shunt field is opened while the motor is running ?

(14) Give three different methods for starting up a rotary transformer.

(15) How does a short-circuited field coil on a shunt dynamo affect the other field coils ?

(16) Describe at least one method for locating a short-circuited armature coil.

(17) In making a bar-to-bar test around an armature, what would be indicated (*a*) by an unusually large deflection of the galvanometer or other testing instrument used ? (*b*) by an unusually small, or no, deflection ?

(18) (*a*) What is the objection to having the pressure between a brush and the commutator too great ? (*b*) What is the objection to having it too small ?

(19) (*a*) What does a narrow scratch or several of them all around a commutator usually indicate ? (*b*) What is the remedy ?

(20) What is the advantage of staggering the brushes on a commutator and having end play for the armature ?

(21) What would a grinding, rumbling noise, accompanied by excessive sparking and, perhaps, some slipping of the belt, indicate in a dynamo or motor ?

(22) What would be the effect of having one field coil reversed in (*a*) a dynamo? (*b*) a motor?

(23) State two reasons why a simple shunt dynamo may refuse to generate when properly rotated at normal speed.

(24) How are synchronous motors generally started?

(25) If only one coil in a motor or dynamo armature, when revolving at normal speed in its own normal field, becomes abnormally hot, what defect is indicated?

(26) What does a broad scratch around the surface of a commutator indicate?

(27) How would you start an induction motor?

DYNAMO-ELECTRIC MACHINERY.

EXAMINATION QUESTIONS.

(1) What is the relation in a direct-current motor armature between the E. M. F. at the brushes, the counter E. M. F., and the drop or fall of potential through the armature ?

(2) Why will not an ordinary series-wound dynamo, without regulating devices, give a constant current through a circuit of varying resistance ?

(3) How is the Thomson-Houston constant-current dynamo regulated to give a constant current ?

(4) A certain series-wound motor is tested with a Prony brake, the distance from the center of the shaft to the point where the arm of the brake rests on the scale platform being 36 inches. The brake is tightened until the pressure on the platform is 27 pounds, when the following readings are taken: Current to motor, 25 amperes; volts at terminals, 480; speed, 900 R. P. M. (*a*) What is the output of the motor in H. P.? (*b*) What is its efficiency at this output ?

Ans. $\begin{cases} (a) & 13.88 \text{ H. P.} \\ (b) & 86.3 \text{ per cent.} \end{cases}$

(5) Draw a diagram showing the connections of a shunt-wound motor with main switch, reversing switch, starting resistance, and fuse box.

(6) How may the speed of a direct-current shunt motor be varied?

(7) When two coils or sets of coils in an open-coil constant-current armature are connected in parallel by the brushes and the E. M. F. in one coil is less than that in the other, why does not a current flow from the coil having the higher E. M. F. around through the other?

(8) How may the speed of a direct-current series-wound motor be varied?

(9) (*a*) What three general methods of regulation are used with closed-coil constant-current dynamos? (*b*) Which of the three is most generally used?

(10) A certain motor, being tested with a Prony brake, is found to have 85 per cent. efficiency when taking an input of 33 amperes at 230 volts. If the arm of the brake is 2 feet long, from center of shaft to point where it rests on the scale platform, and the pressure on the scale platform is 20 pounds, at what speed (to the nearest whole revolution) is the motor running? Ans. 1,136 rev. per min.

(11) Why is the starting resistance of a shunt-wound motor not included in the field circuit?

(12) Why is it that there is no E. M. F. generated in the coil of a Westinghouse constant-current dynamo that is directly under a pole piece?

(13) What is the character of the current in the external circuit of open-coil constant-current dynamos?

(14) How many sets of brushes must be provided for a parallel- or lap-wound drum armature?

(15) How many sets of brushes need be provided for a series- or wave-wound drum armature?

(16) What limits the output of constant-current dynamos?

(17) What would be the successive combinations that any particular coil in the Thomson-Houston constant-current

dynamo makes with the other coils during a half revolution, starting from a position where it is not active?

(18) A certain shunt-wound motor takes a current of 5 amperes at 125 volts when running free. Its armature resistance is .04 ohm and its field resistance 62.5 ohms. (*a*) What would be its output in H. P. when taking a current of 77 amperes at 125 volts? (*b*) What would be its efficiency at this output?

NOTE.—As the method of finding the output and efficiency that should be used in solving the above problem is not strictly accurate, four figures are enough to retain in calculations or results.

Ans. $\begin{cases} (a) & 11.76 \text{ H. P.} \\ (b) & 91.17 \text{ per cent.} \end{cases}$

(19) How is the E. M. F. of the Excelsior constant-current dynamo regulated to give a constant current?

(20) How much current, relative to the total current output of the armature, flows in an armature conductor of a parallel- or lap-wound armature for a six-pole machine?

(21) To reverse the direction of rotation of a motor, what changes in the connections are necessary?

(22) What limits the output of a direct-current constant potential motor?

(23) On what quantities does the torque of a direct-current motor depend?

(24) How may the applied E. M. F. of a direct-current motor be varied?

(25) (*a*) In a series-wound drum armature does the strength of current in the armature conductors depend on the number of brushes used? (*b*) How much current, relative to the total current output of the armature, flows in the armature conductors of a series-wound drum armature?

(26) To what classes of work are (*a*) shunt-wound direct-current motors applicable? (*b*) series-wound motors?

(27) How are the devices for shifting the brushes of constant-current dynamos with closed-coil armatures usually thrown into or out of action ?

(28) Which armature winding, a parallel or series, is most suitable and why (*a*) for a machine that has to furnish a comparatively large current at a comparatively low voltage, and (*b*) for a machine that has to furnish a comparatively small current at a comparatively high voltage ?

(29) Why should the field circuit of a shunt-wound motor never be opened as long as the armature is connected in the circuit ?

STEAM HEATING.

EXAMINATION QUESTIONS.

(1) Describe briefly the one-pipe system of steam heating and explain how the water of condensation is returned to the boiler.

(2) What is the principal difference between the one-pipe, two-pipe, separate-return, and drop systems of heating?

(3) Mention some of the defects of the one-pipe system of heating.

(4) About what pitch are main steam pipes usually given?

(5) In case a horizontal pipe is too long to be given a uniform grade for drainage purposes, how can it be drained?

(6) (*a*) Should a long riser be connected directly to the top of the steam main by a **T**? (*b*) Why?

(7) Explain how a radiator in a one-pipe system may become filled with water.

(8) What is the objection to a return main located above the water level?

(9) What diameter of main steam pipe is required to supply direct radiators having a total heating surface of 5,000 square feet? Ans. 8-in. pipe.

(10) What is the usual amount of expansion allowed for in steam piping?

(11) If a pipe 6 inches in diameter is used, what amount of direct heating surface may be supplied by it?

Ans. 2,827.4 sq. ft.

(12) In what two ways should a system of piping be tested before it is covered by plastering or flooring ?

(13) (*a*) What is the object of making radiators with extended surfaces ? (*b*) Has a radiator with extended surfaces any advantage over a radiator having plain surfaces, if the air is simply moved by convection ?

(14) Explain why the most effective form of radiator or coil for direct heating is one having a single row of tubes placed in a horizontal position.

(15) What are the advantages of flue radiators with regard to efficient heating surface ?

(16) (*a*) If a flat heating coil is to be used with the row of tubes placed vertically, why should not the opposite ends of the tubes screw directly into manifolds ? (*b*) How should the coil be constructed ?

(17) Describe the Nason tube.

(18) How may a radiator of the Bundy type be adapted to direct-indirect heating ?

(19) In a two-pipe system, why should the return riser be shut off when the valve in the steam riser is closed ?

(20) If it is necessary to place two radiators in one room, why is it a good plan to divide the total heating surface required between the radiators, so that one will be, say, twice as large as the other ?

(21) How many square feet of heating surface should a radiator have to heat a room that is 20 feet wide, 30 feet long, and 10 feet high ? There are two exposed walls (a side and an end) and three windows $3\frac{1}{2}$ ft. × 6 ft. The lowest outside temperature is 0° F., the temperature of the steam used is 225° F., and the temperature of the room is to be 70° F. The walls are of brick and are lathed and plastered. Allow 30 per cent. for air leakage and 25 per cent. for exposure to winds. Ans. 78.4 sq. ft.

(22) If a hammering or hissing sound is heard in a raditor when the valve is closed, what is probably the trouble ?

(23) If a radiator does not heat when the steam is turned on, what is out of order?

(24) Where should the air vent be placed on a radiator with reference to the steam inlet?

(25) (*a*) What is the principal objection to the ordinary air vent? (*b*) How may it be remedied?

(26) What can you say as to the beneficial results obtained by injecting cold feedwater into the receiver of a vacuum system to improve the vacuum?

STEAM TURBINES

EXAMINATION QUESTIONS

(1) Does the De Laval steam turbine use the steam expansively?

(2) What is the object of the flexible bearing fitted to the shaft of the De Laval turbine?

(3) Why are the gears of a De Laval turbine made with right-handed and left-handed helical teeth?

(4) What means have been adopted in condensing De Laval turbines to give a close regulation during a very large and sudden decrease of load?

(5) What is the object of the flexible shaft fitted to the De Laval turbine?

(6) What is accomplished by the De Laval expansion nozzle?

(7) Is there any difference in the manner in which expansion of the steam is obtained in the De Laval and the Westinghouse-Parsons steam turbines? If so, explain it.

(8) How is vibration at high speeds prevented in the Westinghouse-Parsons turbine?

(9) Is steam admitted in a continuous stream to a Westinghouse-Parsons turbine? If not, how is it admitted?

(10) How is the steam expanded in the Curtis turbine?

(11) Do the stationary blades of the Curtis turbine extend around the circumference of the wheels carrying the moving blades?

(12) How does a steam turbine differ in the use of steam from a reciprocating engine?

2 -31

A KEY

TO ALL THE

QUESTIONS AND EXAMPLES

CONTAINED IN THE

EXAMINATION QUESTIONS

INCLUDED IN THIS VOLUME.

The Keys that follow have been divided into sections corresponding to the Examination Questions to which they refer, and have been given corresponding section numbers. The answers and solutions have been numbered to correspond with the questions. When the answer to a question involves a repetition of statements given in the Instruction Paper, the reader has been referred to a numbered article, the reading of which will enable him to answer the question himself.

To be of the greatest benefit, the Keys should be used sparingly. They should be used much in the same manner as a pupil would go to a teacher for instruction with regard to answering some example he was unable to solve. If used in this manner, the Keys will be of great help and assistance to the student, and will be a source of encouragement to him in studying the various papers composing the course.

DYNAMOS AND MOTORS.

(1) By formula **1**, $E = \frac{2\,N\,S\,n}{10^8}$. In this example, $N = 6{,}250{,}000$ lines of force, $S = 100$ outside, or face, wires in series, for if 200 turns were wound around the core, there would be 200 outside, or face, wires and from Art. **23** one-half would be connected in series, and $n = \frac{1{,}200}{60}$ revolutions per second. Substituting these values in above formula gives $E = \frac{2\,N\,S\,n}{10^8} = \frac{2 \times 6{,}250{,}000 \times 100 \times 1{,}200}{100{,}000{,}000 \times 60}$ $= 250$ volts. Ans.

(2) From Art. **36**, it will be seen that the current in the shunt field of a dynamo is equal to the difference of potential between the brushes divided by the resistance of the shunt field circuit, or $C_s = \frac{E}{R_s}$. In this example, $E = 220$ volts and $R_s = 440$ ohms; hence, $C_s = \frac{E}{R_s} = \frac{220}{440} = .5$ ampere. Ans.

(3) An alternating current is one that is continually reversing in direction in a regular periodic manner, flowing first in one direction in a circuit and then in the other, while a continuous current is one that flows, without stopping, in one direction. See Arts. **13** and **14**.

(4) In Art. **1**, it is stated that a current will be induced in a closed coil or circuit when there is a change in the number of lines of force passing through that coil or circuit. In this case, as the magnetic field is uniform, there is no change in the total number of lines of force passing through, or enclosed by, the coil C when it is moved from its original position to the position C', as shown by the dotted outlines; and, hence, no current will flow around the ring.

(5) In this example, it is first necessary to determine the input in watts. By formula **4**, the input $I = \frac{100 \times 17{,}500}{87.5}$ $= 20{,}000$ watts. Since 2.6 per cent. of the input is used to excite the field magnets and the input is 20,000 watts, then the watts consumed in exciting the field magnets will be 2.6 per cent. of 20,000 watts; hence, as in Art. **64**, the field loss $= \frac{20{,}000 \times 2.6}{100} = 520$ watts. Ans.

(6) In Art. **67**, $C_s = \frac{E_e}{r_s}$. In this example, $C_s = \frac{110}{55}$ $= 2$ amperes. The watts lost in the shunt circuit are equal to the difference of potential between the terminals of that circuit multiplied by the current in amperes flowing through the circuit; or, $W = E \times C$. Substituting, we have $W = 110 \times 2 = 220$ watts. Ans.

(7) A commutator is usually a cylinder formed of a number of copper bars insulated from one another and running longitudinally or parallel with the axis of the cylinder. Each copper bar is joined to the armature winding at regular intervals and the commutator is fastened to the shaft of the armature so as to rotate with it.

The commutator is used to transform the alternating current that is generated in the armature coils of a dynamo so that a continuous current may be obtained in the circuit external to the armature, or conversely to transform a continuous current that flows in an external circuit into an alternating current as it passes into the winding of a motor armature. See Arts. **14** and **19**.

(8) Use formula **4.** In this example, the input $= \frac{100 \times 65,000}{90.5} = 71,823.2$ watts. Since 1 horsepower equals 746 watts, then 71,823.2 watts equal $\frac{71,823.2}{746} = 96.28$ H. P. Ans.

(9) If the current circulates in the direction indicated by the arrowheads, *neither* pole piece will be a north pole; for it will be seen that the north pole of one field coil is opposite the south pole of the other, and the lines of force circulate around the magnets without passing through the armature. If the winding of the right-hand coil were reversed, its top would be a north pole, and the top of the left-hand coil being also north, the pole piece P would become a north consequent pole and P' a south consequent pole.

(10) In this example, it is first necessary to change the input from horsepower to watts. Since 1 horsepower is equivalent to 746 watts, then 10 horsepower are equivalent to $10 \times 746 = 7,460$ watts. Then, by formula **2,** the efficiency $\mathbf{E} = \frac{100 \times 6,341}{7,460} = 85$ per cent. Ans.

(11) From b to a through the conductor; for, by applying the thumb-and-finger rule given in Art. **8** as indicated, it will be seen that the middle finger is pointing toward a from b.

(12) In this example, it is first necessary to find the input in watts. In this example, the output = 11,900 watts and the per cent. efficiency = 85. Then, by formula **4,** the input $= \frac{100 \times 11,900}{85} = 14,000$ watts input. As in Art. **64,** the watts lost are found by multiplying the input by the percentage of loss and dividing by 100. Hence, $\frac{14,000 \times 1.8}{100}$ = 252 watts lost in core by eddy currents and hysteresis. Ans.

(13) (*a*) When a current is being generated in the armature of a dynamo, the reaction between this current and the

lines of force produced by the field oppose the rotation of the armature conductors, in fact, it tends to rotate the armature in the opposite direction. This opposing effect of the current in the armature of a dynamo is known as the counter torque of a dynamo. See Art. **28.**

(*b*) If a conductor is forcibly moved, as in a dynamo armature, across a magnetic field in a given direction, say in the direction of the arrows *a*, *a*, Fig. 33, a current will flow in the conductor from c to c'. If this same conductor is not forcibly moved, but lies in this same field, and a current is sent through it in the same direction as before, that is from c to c', then the conductor will move across the field in the direction of the arrows *b*, *b*, if there is nothing to oppose its motion. The force causing this latter motion evidently will oppose the force producing the motion of the conductor in the dynamo armature. These two opposing forces are evidently present in a dynamo armature, the counter torque being the smaller, of course, else the armature would not revolve. See Art. **25.**

(14) $W = C^2 r$. In this example, $C = 120$ amperes and $r = .040$ ohm; hence, $W = 120^2 \times .040 = 576$ watts. Ans.

(15) Under "Field Losses," in Art. **66,** the watts lost in the series coils is found by using the formula $W = C^2 R$. In this example, $C = 40$ amperes and $R = .04$ ohm; hence, $W = 40^2 \times .04 = 40 \times 40 \times .04 = 64$ watts, which represents the loss in the series coils. The watts lost in the shunt coil is given by the formula $W = \frac{E^2}{R}$. In this case, $E = 550$ volts and $R = 550$ ohms; hence, $W = \frac{E^2}{R} = \frac{550 \times 550}{550} = 550$ watts, which is the loss in the shunt field. The total loss in the fields of a compound-wound dynamo is equal to the sum of the losses in the series and shunt coils. Hence, the total loss in this case is $64 + 550 = 614$ watts. Ans.

(16) When current flows in the armature conductors, the armature core is magnetized by this current in such a

direction as will produce lines of force exactly at right angles to the lines of force produced by the field, if the two magnetizing forces could act independently of each other. But lines of force cannot cross each other, hence the two systems of lines of force rearrange themselves and produce, as a result, neutral points that are shifted forwards, in the case of a dynamo, in the direction of rotation when current flows or increases in strength in the armature conductors. See Art. **29.**

(17) From Art. **63,** the total loss in a dynamo is the sum of the separate losses; hence, in this example, the total loss in watts is $356 + 178 + 263 + 423 + 50 = 1{,}270$ watts. From Art. **59,** the input to the dynamo in this case is $15{,}000 + 1{,}270 = 16{,}270$ watts. By formula **2,** the efficiency $E = \frac{100 \times 15{,}000}{16{,}270}$, or 92.19 per cent. at this output. Ans.

(18) From example 17, the loss in mechanical friction is 356 watts, and the input is 16,270 watts; hence (see Art. **72**), the percentage loss is $\frac{356 \times 100}{16{,}270}$, or 2.1881 per cent. Ans.

From example 17, the loss in the core by eddy currents and hysteresis is 178 watts, and the input is 16,270 watts; hence, the percentage of loss is $\frac{178 \times 100}{16{,}270}$, or 1.094 per cent. Ans.

From example 17, the loss in the field coils is 263 watts, and the input is 16,270 watts; hence, the percentage of loss is $\frac{263 \times 100}{16{,}270}$, or 1.6165 per cent. Ans.

From example 17, the loss in the armature $(C^2 r) = 423$ watts, and the input is 16,270 watts; hence, the percentage of loss is $\frac{423 \times 100}{16{,}270}$, or 2.5999 per cent. Ans.

From example 17, the sum of the separate losses is 1,270 watts, and this is the difference between the input and the output; the input is 16,270 watts; then, by formula **3,** the total percentage of loss $L = \frac{100 \times 1{,}270}{16{,}270}$, or 7.8058 per cent. Ans.

(19) From Art. **22**, it will be seen that the electromotive force generated in an armature is proportional to the speed, other conditions and quantities remaining unchanged. Hence, in this example, if E represents the electromotive force that is generated when the armature is driven at 1,400 revolutions per minute, then, by proportion, $440 : E :: 1{,}200 : 1{,}400$, or $E \times 1{,}200 = 440 \times 1{,}400$; therefore, $E = \frac{440 \times 1{,}400}{1{,}200} = 513\frac{1}{3}$ volts. Ans.

(20) They spark less than copper brushes, especially when the load is a variable one. See Art. **79.**

(21) Yes; because, Art. **1,** a change takes place in number of lines that pass through the coil. From the rule given in Art. **7,** it will be seen that the current will circulate around the ring in the same direction as the movements of the hands of a watch; for the effect of the motion is to diminish the number of lines of force that pass through the coil, and the observer is looking along the magnetic field in the direction of the lines of force.

(22) See Art. **42.**

(23) The *rate of cutting* lines of force is found by dividing the number cut by the time required to cut them; hence, in this case, the rate of cutting is $\frac{8{,}000{,}000}{.25}$ $= 32{,}000{,}000$ lines of force per second.

(24) Because the solid iron core would act as a large conductor cutting lines of force, thereby producing *local*, or *eddy*, currents in the core, heating it badly, and uselessly dissipating a large amount of energy. See Art. **16.**

(25) From Art. **22,** it will be seen that the electromotive force generated in an armature is proportional to the number of lines of force passing through the core. Let E represent the electromotive force that is generated when 1,250,000 lines of force are passing through the core; then, by proportion, $200 : E :: 750{,}000 : 1{,}250{,}000$, or

$E \times 750{,}000 = 200 \times 1{,}250{,}000$; therefore, $E = \frac{200 \times 1{,}250{,}000}{750{,}000}$ $= 333\frac{1}{3}$ volts. Ans.

(26) (*a*) See Art. **65.**
(*b*) See Art. **70.**
(*c*) See Art. **66.**

(27) Toward the side a; for, by applying the thumb-and-finger rule given in Art. **26,** and making the forefinger point in the direction of the lines of force and the middle finger in the direction of the current, the thumb will point toward the side a.

(28) Use the formula given under "Field Losses" in Art. **67,** $C_s = \frac{E_e}{r_s}$, which is a modification of the formula $C = \frac{E}{R}$. In this example, $E_e = 525$ volts and $r_s = 650$ ohms; hence, $C_s = \frac{E_e}{r_s} = \frac{525}{650} = .8076$ ampere. Ans.

(29) The increase in voltage from no load to full load is $124.2 - 115 = 9.2$ volts, which is $\frac{9.2 \times 100}{115} = 8$ per cent. of the normal voltage. Therefore, the over-compounding is 8 per cent. Ans.

(30) It is radiated from the surface into the surrounding air, and some of it may be conducted away through the shaft, bearings, and base.

(31) See Arts. **34, 36,** and **39.**

(32) From Art. **72,** the percentage of loss in the core is found by dividing the number of watts lost in the core by the input and multiplying by 100. Reducing 64 horsepower to watts gives $64 \times 746 = 47{,}744$ watts. Consequently, the loss in the core is $\frac{800 \times 100}{47{,}744} = 1.6756$ per cent. Ans.

(33) See Art. **76.**

(34) See Art. **43.**

OPERATION OF DYNAMOS AND MOTORS.

(1) The dust from coal and from the machines mentioned is very injurious to the bearings of engines and electrical machines and also to the commutators and general insulation of the latter. See Art. **1.**

(2) (*a*) Copper brushes are generally used on electric-light dynamos where the current output is large and the voltage low.

(*b*) They are generally set tangential, or approximately so, never radially.

(3) (*a*) Copper brushes are trimmed to fit the commutator by shaping and filing them in an iron jig, properly shaped to fit the surface of the commutator.

(*b*) Carbon brushes are usually made to fit the commutator by putting the brush in position and then drawing a piece of sandpaper (never emery paper) between the brush and the commutator against which the brush-holder spring presses the brush, the sanded side of course being next to the carbon brush.

(4) The odor of hot oil around a machine usually indicates an abnormally hot bearing.

(5) It may be due to the lack of power on the line or an open or short circuit in the field of the machine or in the

connections between the circuit and the motor. See Art. **58.**

(6) Sparking at the brushes may be due to any one of the following causes: too much load, brushes improperly set, commutator rough or eccentric, high or low commutator bars, poor contact between brushes and commutator, dirty brushes or commutator, speed too high, sprung armature shaft, armature too low because of worn bearings, worn commutator, short or open-circuited or reversed armature coil, brushes of too high resistance, a shaky foundation that allows the machine to vibrate excessively, a slipping belt.

(7) The bar-to-bar test is probably the most convenient one, all things being considered. See Arts. **97** to **99,** inclusive.

(8) By connecting a voltmeter across each of the coils in succession. The coil across which a deflection is obtained is the open-circuited coil. In the absence of a voltmeter, incandescent lamps may be used. For example, in Fig. 24 a deflection will be obtained between c and b, but none between b and a. See Art. **92.**

(9) Oil is apt to saturate the insulating material between the bars and to become charred, while the emery will collect between the bars. The charred oil and emery are more or less of a conductor, hence the insulation between the bars becomes lower. Emery generally contains iron impurities that make it a conductor. Small pieces of emery may also become lodged in the brushes and scratch the commutator. See Art. **10.**

(10) Carbon brushes have a comparatively high resistance, hence the current in the coils that are short-circuited by the brushes at or near the neutral points is not so great as to produce excessive sparking, even when the brushes due to a momentary change in the load are not in the best, or neutral, position.

(11) (a) High bars can usually be filed, sandpapered, or turned down to the surface of the other bars.

(*b*) To remedy a low bar it is usually necessary to turn down, file, or sandpaper the whole commutator to a smooth and true surface.

(12) The commutator becomes rough, the brushes heat and spark, the belt squeaks, and the machine grows hot all over.

(13) Severe sparking is caused and the circuit-breaker opened because the motor armature generates but little counter E. M. F., and forms practically a short circuit across the supply mains. In some cases the motor may speed up excessively.

(14) A rotary converter may be started by connecting the alternating-current side to the line; by supplying the direct-current side with direct current from another rotary or from a storage battery; by starting up the alternator. See Art. **89.**

(15) The other coils become warm. See Art. **41.**

(16) By holding a piece of iron near the armature; the piece of iron will vibrate when the coil passes it. See Art. **23.** Another method is to use the device described in Art. **97.**

(17) (*a*) An unusually large deflection would indicate an open circuit in the armature coil whose terminals are supposed to be connected to the commutator bars upon which the testing clips rest.

(*b*) No deflection would indicate one of three things: either a dead cross in the coil connected to the commutator bars upon which the testing clips rest, or a cross between the two bars themselves, or that there was an open circuit in the same half of the armature in which the testing clips were being used, but somewhere else except between the test clips. A smaller deflection than that given by a good coil would indicate a partially short-circuited coil or poor insulation between the turns or between the commutator bars under the test clips.

(18) (*a*) If the pressure is greater than necessary, the wear on the commutator and the friction to be overcome will be unnecessarily great.

(*b*) If the pressure is too small, there will be sparking and heating because of the bad contact between brush and commutator.

(19) (*a*) Such scratches usually indicate that there are particles of hard foreign matter under one or more of the brushes.

(*b*) The remedy is to remove the brushes and clean them thoroughly.

(20) The brushes will play or bear over the whole wearing surface of the commutator, thus preventing the wearing of the commutator in ruts.

(21) It would indicate that the bearings had worn down or that a field core had become loose, thus allowing the armature to rub against the core or pole piece.

(22) (*a*) In a dynamo, one field coil reversed would reduce the voltage and perhaps render the machine incapable of generating at all.

(*b*) In a motor, one field coil reversed would increase the current required to start the motor, would abnormally increase the speed after it is started, and would cause the brushes to spark. A motor with but two field coils may refuse to start or else start very slowly if one of its field coils is reversed.

(23) All residual magnetism may have disappeared or the field and armature may be improperly connected together. Reversing either the armature or the field, not both, after they were once properly connected, would destroy whatever residual magnetism there may have been and, consequently, the machine would refuse to generate. For other causes and remedies see Arts. **49** to **52**, inclusive.

(24) Ordinary synchronous motors will not start up by themselves under load. They must be brought up to synchronism under no load, either by themselves, by switching on the line current, or by some outside source of power, as, for example, by a small induction motor.

(25) It would indicate that the one armature coil was short-circuited.

(26) A broad scratch around the surface of a commutator indicates that probably one of the brush holders has been set too close or has become loose and slipped down, so that it touches the commutator.

(27) An induction motor is started up by first seeing that the starting compensator, resistance, or other device is in circuit, then throwing in the main switch and cutting out the compensator or resistance as the motor comes up to speed.

DYNAMO-ELECTRIC MACHINERY.

(1) This relation is expressed by the formula $E = E_m + C R_a$; that is, the E. M. F. supplied at the brushes is equal to the counter E. M. F. generated in the motor armature plus the E. M. F. required to force the current through the armature against its resistance. This last quantity, $C R_a$, called the drop or fall of potential through the armature, is equal to the product of the current C and the resistance of the armature R_a.

(2) Because if the external resistance is increased, the current will decrease; this will weaken the field, since the field and armature are directly in series, and, hence, lower the E. M. F. generated by the armature, which still further decreases the current. If the external resistance is decreased, the current and E. M. F. will each be increased.

(3) When the current increases beyond a certain strength, a regulating magnet, connected directly in the main circuit, draws up its cores, thereby opening a short, or shunt, circuit around quite a powerful controlling magnet. This allows the regulating magnet, which is now supplied with current from the main circuit, to attract its keeper, thereby separating, by means of a system of levers, the two brushes of each set. This separating of the brushes of each set short-circuits the armature for a very brief interval of time. The more the brushes are

separated the longer is the armature short-circuited. In any case, however, this interval is extremely short, although it may occur as often as 5,100 times per minute. The great self-induction of the field and armature prevents the fall of the current to zero each time the armature is short-circuited. As the current tends to increase the greater becomes the length of the short-circuiting intervals and, hence, the average value of the current remains approximately constant. See Arts. **21** and **22.**

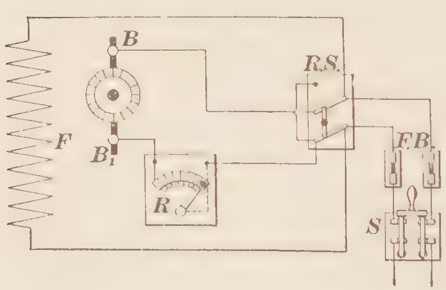
(4) (*a*) The length of the arm of the brake being 36 inches, or 3 feet, the torque of the motor is $27 \times 3 = 81$ pound-feet. Arts. **33, 34,** and **35.** The revolutions per minute being 900, the horsepower output of the motor is, from formula **2,**

$$\text{H. P.} = \frac{2 \times 3.1416\ TS}{33,000} = \frac{6.2832 \times 81 \times 900}{33,000} = 13.88 \text{ H. P.}$$

Ans.

(*b*) To find the efficiency, it is first necessary to find the input and reduce the input and the output to the same units. Art. **35.** In this case the input is $25 \times 480 = 12,000$ watts. Reducing 13.88 horsepower to watts, $13.88 \times 746 = 10,354$ watts. Then, the efficiency **E** $= \frac{100 \times 10,354}{12,000} = 86.3$ per cent. Ans.

(5) The connections would be about as shown in the figure, in which F is the field circuit, B, B_1 the brushes of the motor, R the starting resistance, R S the reversing switch, F B the fuse boxes, and S the main switch.



(6) The speed of a direct-current shunt-wound motor may be varied by changing the field strength or by changing the E. M. F. applied to the armature by inserting an adjustable resistance in the armature circuit.

(7) Because the self-induction of the coil having the lesser E. M. F. prevents the flow of current. Art. **14.**

(8) The speed of a direct-current series-wound motor may be varied by varying the strength of the field, by altering the effective number of turns in the field coils, or by inserting an adjustable resistance in the circuit in series with the motor.

(9) (*a*) See Art. **3.**

(*b*) See Art. **5.**

(10) The input to the motor being $33 \times 230 = 7,590$ watts, and the efficiency being 85 per cent., the output is $\frac{7,590 \times 85}{100} = 6,451.5$ watts. This is equal to $\frac{6,451.5}{746}$ $= 8.65$ horsepower. The arm of the brake being 2 feet long and the pressure on the scale platform being 20 pounds, the torque of the motor must be 40 foot-pounds $= T$. Knowing the horsepower and the torque, the speed may be found from formula **3,** $S = \frac{33,000 \times \text{H. P.}}{2 \times 3.1416\ T}$. Substituting the above values for H. P. and T, S $= \frac{33,000 \times 8.65}{2 \times 3.1416 \times 40} = \frac{285,450}{251.328} = 1,136$ rev. per min. Ans.

(11) If the starting resistance were in series with the whole shunt-wound motor instead of in series with the armature only, there would be on starting the motor only a small current through the field coils and, consequently, the field would be so weak that an excessively large current would be required in the armature to furnish the necessary torque for starting.

(12) Because as the coil moves across the center of a pole piece, as many lines of force pass out across one side of the coil as pass in across the other side of the coil; that is, there is no change in the actual number of lines of force that pass through the coil. Or, we may consider that since one side of the coil is cutting lines of force just as fast and in the same direction as the other side, hence the E. M. F.'s

generated in each side are exactly equal and opposite, and hence there is no resultant E. M. F. or current generated in the coil. See, also, Art. **17.**

(13) It is a pulsating current; that is, the current flows always in one direction in the line circuit, but it fluctuates rapidly (many times a second) in strength. When such a current is referred to as a constant current, it is meant that the average strength of the current is constant. See Art. **12.**

(14) A parallel- or lap-wound drum armature must be provided with as many sets of brushes as there are poles on the machine.

(15) A series- or wave-wound drum armature need be provided with only two sets of brushes. However, any number of sets, not exceeding the number of poles on the machine, may be used, and it is preferable, especially on large generators, to use as many sets of brushes as there are poles.

(16) The maximum E. M. F. that the constant-current dynamo is capable of generating limits its output. See Art. **23.**

(17) When in the position of least action, a coil is momentarily disconnected from the external circuit, then thrown in parallel with the coil ahead of it, then in series with the other two coils that are then in parallel, then in parallel with the coil behind it, and then disconnected from the circuit again. See Art. **20,** also Fig. 7.

(18) (*a*) Of the 5 amperes input, by Ohm's law, $\frac{125}{62.5} = 2$ amperes go to the field, the loss being, therefore, $2 \times 125 = 250$ watts. The rest, or $3 \times 125 = 375$ watts, make up the friction and core losses of the machine. Art. **37.** When taking an input of 77 amperes at 125 volts, or 9,625 watts, there would still be required 250 watts for the field and 375 watts for the core losses and friction. Of the 77 amperes, 75 flow through the armature, and as this has

a resistance of .04 ohm, the armature $C^2 r$ would be $75^2 \times .04 = 225$ watts. The total losses would then be $250 + 375 + 225 = 850$ watts, and the output would therefore be $9{,}625 - 850 = 8{,}775$ watts, or $\frac{8{,}775}{746} = 11.76$ H. P. Ans.

(*b*) The output being 8,775 watts and the input 9,625, the efficiency is $\frac{100 \times 8{,}775}{9{,}625} = 91.17$ per cent. Ans.

(19) The E. M. F. of the Excelsior constant-current dynamo is regulated by a controlling magnet that causes current to flow through a small motor in one direction as the current increases, and in the opposite direction as the current decreases. When the small motor revolves in one direction, due to an increasing current, it not only shifts the brushes from the neutral point, but it also cuts out some of the turns of the field coil. These two changes reduce the E. M. F. generated in the armature and, hence, keep the current from increasing beyond its proper constant value. When the small motor revolves in the opposite direction, due to a decreasing current, the operations mentioned are reversed and, hence, the current is kept from decreasing below its proper constant value. See Art. **10.**

(20) The current flowing in an armature conductor in a parallel- or lap-wound armature is equal to the total armature current divided by the number of poles, hence the current in this case would be one-sixth of the total current.

(21) To reverse the direction of rotation of a motor, the direction of the current must be reversed either through the field coils or through the armature; the current must not be reversed in both the field and armature. Hence, to reverse the direction of rotation of the motor reverse the connections with respect to the external circuit of either the field or armature terminals.

(22) The output of a constant-potential motor is limited by the heating of the armature and field and the sparking between the brushes and commutator. See Art. **37.**

(23) See Art. **33.**

(24) The E. M. F. supplied to the terminals of a motor may be varied by inserting an adjustable resistance or rheostat in the line circuit or by varying the E. M. F. of the generator from which the current is obtained. The E. M. F. at the brushes of a shunt-wound motor may be varied without varying the strength of the field by connecting the adjustable resistance only in the path of the current supplied to the armature, the field coils being connected directly to the line wires and not through the adjustable resistance first.

(25) (*a*) No.

(*b*) Half the total current output flows in each armature conductor, since there are but two parallel paths for the current through the armature winding no matter how many pairs of brushes may be used.

(26) (*a*) See Art. **38.**

(*b*) See Art. **38.**

(27) See Art. **6.**

(28) (*a*) A parallel winding is most suitable because there are as many paths in parallel as there are poles, and hence each conductor has to carry only a part of the total current.

(*b*) A series winding is most suitable, because a large number of conductors connected in series are required in order to give the high voltage, and although each conductor must carry half the total current output, still the latter is comparatively small where the voltage is high.

(29) See Art. **42.**

STEAM HEATING.

(1) In the one-pipe system, but one line of pipe is used to connect the boiler and radiators. This necessitates returning the water of condensation to the boiler through the steam main. See Art. **17.**

(2) The manner of returning the water of condensation to the boiler. See Art. **16.**

(3) The circulation is uncertain, owing to the formation of slugs of water in the pipes; the steam is likely to be wet, as it is always in contact with the returning water; water hammer and sizzling noises are very liable to occur; in the case of large systems, the return of the water of condensation through the steam pipes greatly interferes with the flow of steam to the radiators. See Arts. **21** and **23.**

(4) About $\frac{1}{2}$ inch in 10 feet. See Art. **26.**

(5) By using vertical offsets or relays. See Art. **28.**

(6) (*a*) No. See Art. **30.**

(*b*) The expansion of the riser will either bend the main or raise the radiators connected to it. The weight of the riser will also tend to bend the main. See Art. **30.**

(7) If the steam valve is left slightly open, the steam will be condensed as fast as it enters the radiator; and as the opening is so small, little or no water will escape. See Art. **22.**

(8) If there is a slight difference in the pressure at the various radiators, the steam will flow backwards through the

return pipes and interfere with the drainage or cause water hammer. See Art. **36.**

(9) Using rule **1**, Art. **41**, the diameter is found to be

$\sqrt{\frac{5000}{100} \div .7854} = 7.97$ in., or 8 in. in practice. Ans.

(10) About $1\frac{1}{2}$ inches per hundred feet. See Art. **43.**

(11) Using rule **2**, Art. **42**, we find the surface to be

$6^2 \times .7854 \times 100 = 2{,}827.4$ sq. ft. Ans.

(12) By a hydrostatic test to detect any defective fittings or split pipes, and by a steam test to see if expansion has been properly provided for and that the system is in working order. See Art. **53.**

(13) (*a*) By increasing the emitting surface, the heat is given off more rapidly and with but little decrease in temperature of the heat-transmitting surfaces. See Art. **75.**

(*b*) No; the plain surfaces clear themselves more readily than the extended surfaces and are, therefore, more effective. See Art. **75.**

(14) The air has free access to the tubes, and as it does not pass over but one row of tubes, each tube will operate upon air of equally low temperature, thus making the rate of emission of heat a maximum. See Art. **78.**

(15) The interior of the radiator is well supplied with air and the flues impart a high velocity to the warmed air, which greatly increases the efficiency of the flue heating surfaces. See Art. **80.**

(16) (*a*) The top tubes will be warmer than the bottom ones and thus expand more, which will cause the pipes to bulge and the coil to leak. See Art. **83.**

(*b*) A miter coil should be used. See Art. **82.**

(17) The Nason tube is simply a tube capped at one end and divided into two passages by a sheet-iron plate that extends nearly to the end of the tube. The lower end of

the tube is screwed directly into the radiator base. See Art. **86.**

(18) By enclosing the base so that the fresh air, as it enters, is compelled to pass between the hot tubes before escaping into the room. See Art. **91.**

(19) Because the steam pressure may back up the water of condensation into the radiator through the returns and flood the building. See Art. **99.**

(20) If a single large radiator were used, it would probably be difficult to regulate the temperature during mild weather. By using two radiators, one being larger than the other, the small one may be used during mild weather, the large one during moderate cold weather, and both during severe weather. See Art. **96.**

(21) The amount of glass surface is $3\frac{1}{2} \times 6 \times 3 = 63$ square feet. The exposed wall surface reduced to a glass surface is $\frac{10\ (20 + 30) - 63}{10} = 43.7$ square feet. The total cooling surface is $63 + 43.7 = 106.7$ square feet. By rule **3**, Art. **94,** the number of square feet of radiating surface required is $\frac{70 - 0}{225 - 70} \times 106.7 = 48.2$ square feet, nearly. Adding 30 per cent. for air leakage, we have $48.2 + 48.2 \times .30 = 62.7$ square feet, and now allowing 25 per cent. to allow for exposure to winds, we have $62.7 + 62.7 \times .25 = 78.37$, say 78.4 square feet. Ans. See Arts. **95** and **96.**

(22) The radiator valve leaks. See Art. **99.**

(23) The air valve is probably choked or closed. See Art. **98.**

(24) As far as possible from the steam inlet so that the air vent will not close before all the air has escaped. See Art. **70.**

(25) (*a*) The ordinary air vent allows water as well as air to escape.

(*b*) It may be remedied by placing a float on the air-valve stem so that the water will lift the stem and close the valve when it tries to escape. See Arts. **68** and **69.**

(26) The beneficial results are doubtful, as the air contained in the injection water is liberated and expands when the water is heated and thus tends to counteract the effect of condensation. See Art. **64.**

STEAM TURBINES

(1) Yes. See Arts. **3** and **9.**

(2) To close the opening in the casing through which the shaft passes. See Art. **5.**

(3) To confine the shaft longitudinally. See Art. **5.**

(4) A vacuum valve is fitted, which admits air to the casing, the air acting as a brake upon the turbine wheel. See Art. **7.**

(5) It permits the turbine wheel to run at a very high speed without vibration. See Art. **8.**

(6) It greatly increases the velocity of the steam discharged from it. See Art. **9.**

(7) Yes. In the De Laval turbine expansion takes place before the steam impinges on the blades; in the Westinghouse-Parsons turbine expansion takes place while the steam passes from one set of blades to the other. See Art. **11.**

(8) By careful balancing and the use of bearings capable of lateral accommodation. See Art. **14.**

(9) No. Steam is admitted in puffs. See Art. **16.**

(10) It is first expanded in expansion nozzles, and then in passing from one set of blades to the next. See Arts. **17** and **18.**

(11) Only the last set. See Art. **19.**

(12) In the steam turbine the steam gives up its kinetic energy and thus does work; in the reciprocating engine the pressure of the steam is transformed into work. See Art. **20.**

INDEX

NOTE.—All items in this index refer first to the section (see the Preface) and then to the page of the section. Thus, "Alternators 10 56" means that alternators will be found on page 56 of section 10.

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